BENTHIC FORAMINIFERAL FAUNAL CHANGES DURING THE EOCENE/OLIGOCENE CLIMATE TRANSITION AT OCEAN DRILLING PROGRAM (ODP) SITES 1209A AND 1211A FROM THE SHATSKY RISE, CENTRAL PACIFIC OCEAN

A Thesis

by

MEAGHAN ELIZABETH JULIAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Geology

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Approved by:

Chair of Committee,	Anne L. Raymond
Committee Members,	Thomas D. Olszewski
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ABSTRACT

Benthic Foraminiferal Faunal Changes During the Eocene/Oligocene Climate Transition at Ocean Drilling Program (ODP) Sites 1209A and 1211A at the Shatsky Rise, Pacific Ocean. (August 2007)

Meaghan Elizabeth Julian, B.A., State University of New York College at Geneseo

Chair of Advisory Committee: Dr. Anne L. Raymond

The transition from the hothouse climate of the Eocene to the icehouse climate of the Oligocene is pivotal in Earth's history, marked by the initial build up of continental glaciers during the Cenozoic and possibly a significant component of global deep-water cooling. Studies based on oxygen isotope and Mg/Ca data from benthic foraminifera have reached different conclusions about the relative contributions of ice build up versus cooling. A large decline in marine invertebrate diversity began in the middle Eocene and continued into the early Oligocene. In the Southern Ocean, benthic foraminiferal communities gradually changed from *Bulimina* dominated to *Nuttallides* dominated assemblages.

Sixty-five core samples, taken at 50 cm intervals, were analyzed for benthic foraminiferal assemblages across the Eocene/Oligocene transition at Ocean Drilling Program (ODP) Sites 1209A and 1211A. At Site 1209A, our sample interval indicates that the Eocene/Oligocene transition corresponds to depths of 113.83 to 138.18 mbsf and ages of 29.66 to 36.16 Ma, whereas at Site 1211A, it corresponds to depths of 69.78 to 93.96 mbsf and ages of 28.8 to 38.0 Ma. Analyses of upper Eocene sediment indicate

that the benthic foraminiferal assemblage is dominated by *Globocassidulina subglosa*, *Pleurostomella alternans*, *Bulimina,* and *Nuttallides truempyi*, with a relatively lower abundance of *Stilostomella consobrina*. At the Eocene-Oligocene transition, the sediment contains *Globocassidulina subglosa*, *Nuttalides truempyi*, *Nuttalides umbonifera*, *Bulimina alazanensis*, and *Pleurostomella alternans*. In the lower Oligocene sediment, *Globocassidulina subglosa*, *Nuttalides umbonifera*, *Oridosalis umbonatus*, *Pleurostomella alternans*, and *Stilostomella consobrina* are the dominant species of the assemblage. Correspondence analysis shows a stratigraphic gradient between Late Eocene and Early Oligocene samples. These patterns are similar to those in Weddell Sea sediments; the general abundance of *Bulimina* decreases and *Nuttallides* is dominant throughout the transition. Patterns of abundance across the Eocene/Oligocene boundary at Shatsky Rise (decreased *Bulimina* in Oligocene samples) suggest increased levels of oxygen in bottom water across this boundary, indicating well-oxygenated, deep water circulation by the Early Oligocene.

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DEDICATION

To my parents, Thomas and Carolyn Julian, and my sister, Siobhan, for always being just a phone call away …

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INTRODUCTION

The early Cenozoic was one of the warmest periods in Earth's history, as inferred by the high levels of carbon dioxide and other greenhouse gases (Zachos et al., 2001; De Conto and Pollard, 2003). Oceanic bottom water temperatures were extremely warm from the late Cretaceous to the early-middle Eocene, reaching 13-14°C; from the early-Middle Eocene to the Late Eocene, temperature gradually decreased, changing to approximately 6°C, and accelerated across the Eocene-Oligocene transition to a temperature of 0°C (Zachos et al., 2001). Both significant glaciation and cooling of deep water temperatures by 3-5°C may have occurred over a period of 400,000 years, and event known as Oligocene Isotope Event-1, or Oi-1 (Miller et al., 1991; Zachos et al, 1992; Lear et al., 2000; Zachos et al., 2001; Lear et al., 2004; Coxall et al., 2005; Pälike et al., 2006; Eldrett et al., 2007). This period of cooling continued throughout most of the Oligocene, leading to the formation of major ice sheets (Miller et al., 1991; Lear et al., 2000; Zachos et al., 2001; Lear et al., 2004; Coxall et al., 2005; Pälike et al., 2006). Wade et al. (2007) suggest that cooling began prior to the Eocene-Oligocene transition and that glaciation began at the end of Oi-1; this was based on the extinction event of planktonic foraminifera *Hantkenina* and the dwarfing of *Paragloborotalia*, which is believed to be a response to environmental stress.

Significant glaciation may have started in Antarctica and eventually formed in the Northern Hemisphere or glaciation occurred simultaneously in both hemispheres

This thesis follows the style and format of Palaios.

(Lear et al., 2000; Zachos et al., 2001; Lear et al., 2004; Coxall et al., 2005; Eldrett et al., 2007), although the increase in glaciation is mirrored by the increased intensity of the Antarctic cryosphere, which may have developed as the Antarctic Circumpolar Current (ACC) continued to cool Antarctica (Thomas, 1992; Zachos et al., 2001; Kennett, 2004). This was aided by the opening of the Tasmanian Gateway and, eventually, the Drake Passage, which helped to thermally isolate the Antarctic Continent (Kennett, 2004). As time progressed, polar ice sheets started to expand toward the continents, and the earth entered into one of the coldest periods in history (Zachos et al., 2001).

Deep water formation (i.e. the psychrosphere) has been proposed as a possible contributor to the isotopic shift at the Eocene-Oligocene transition, although the exact timing of psychrosphere formation of remains controversial (Keigwin, 1980; Thomas, 2004). Today, the psychrosphere consists of North Atlantic Deep Water (NADW) and Southern Antarctic Bottom Water (Trujillo and Thurman, 2005). Faunal evidence suggests that the psychrosphere, the layer of cold, deep water at the bottom of the ocean, began to form in the Late Eocene (Benson, 1975; Corliss, 1979). Keigwin (1980) suggested that an enrichment of 1‰ in the $\delta^{18}O$ of benthic foraminifera, which occurred at the E/O boundary in the Pacific Ocean, marks the initial formation of cold deep water masses. This is supported by a small (0.3‰) increase in the $\delta^{18}O$ composition of planktonic foraminifera (Keigwin, 1980). Corliss et al. (1984) attributed the E/O isotopic shift to changing climate because there is minimal restructuring of benthic foraminiferal assemblages. In their view, the initiation of deep cold bottom water predated the isotopic shift. Recent studies concurred that deep water bodies started to

form prior to the E/O boundary, as early as the Late Cretaceous (~70 Ma) based on neodymium isotopes (Thomas, 2004).

In addition to the cooling of air temperatures and bottom waters, noticeable changes occurred among living organisms across the E/O climatic transition. Both marine and terrestrial plants and animals were affected by the environmental stresses caused by the changing climate. Dramatic extinction occurred in calcareous nannoplankton and planktonic foraminiferal groups (Aubry, 1992; Keller and MacLeod, 1992), as well as among gastropod and bivalve taxa (Hansen, 1992). Benthic foraminifera were also affected by this extinction event, although not as seriously as other groups (Thomas, 1985; 1992). Among organisms affected by this event, warm-water taxa were the most seriously affected (Berggren and Prothero, 1992; Prothero, 1994). Extinctions associated with the E-O climate transition are also step-wise, with one extinction event in the early-middle Eocene and a subsequent extinction event occurring in the late Eocene. The terrestrial record indicates that plant floras changed from subtropical floras that had dominated from the Cretaceous through the Eocene to deciduous forests that currently thrive today (Wolfe, 1992; Prothero, 1994). Warm, large-shelled snails of the Late Eocene were replaced by dry, small-shelled snails in the Early Oligocene (Evanoff et al., 1992), while mammals suffered few extinction events (Emry et al., 1987).

There has been much speculation about the potential causes of climate cooling at the Eocene-Oligocene transition. Tectonic changes, specifically those associated with the opening of the Tasmanian Seaway and the Drake Passage may have played a role in

climate cooling. The separation of Australia from Antarctica during the Eocene opened the Tasmanian Seaway and allowed the Antarctic Circumpolar Current (ACC) to develop (Frakes and Kemp, 1972; Kennett and Hodell, 1995; Kennett, 2004; Barker and Thomas, 2004). The ACC greatly influenced climate in the Antarctic, as the widening of the Tasmanian Seaway allowed for mixing of colder, Antarctic waters and the warmer waters of the Pacific and Indian Ocean waters. The continued opening of the Tasmanian Seaway and the increased strengthening of the ACC eventually isolated Antarctica from the warmer temperatures of the rest of the world, which led to an expansion of global cooling (Zachos et al, 2001; Kennett, 2004).

Cenozoic cooling has also been attributed to decreased levels of greenhouse gases. Marked shifts in $\partial^{18}O$ and $\partial^{13}C$ composition occur at the Eocene/Oligocene and the Oligocene-Miocene boundaries, both periods in history when a major glaciation occurred (Zachos et al., 2001). $\partial^{18}O$ values from benthic foraminiferal tests are used to infer bottom water temperatures, while $\partial^{13}C$ values are used to infer levels of atmospheric carbon dioxide (Zachos et al., 2001; DeConto and Pollard, 2003; Coxall et al., 2005). During the Cenozoic, CO_2 levels decreased, causing a decrease in overall temperatures, which assisted the buildup of ice sheets on the continents (Zachos et al., 2001). This decrease in carbon values is mirrored by an increase in oxygen values, indicating a decrease in global temperature. DeConto and Pollard (2003) suggested that declining atmospheric CO_2 was the main cause of the build-up of glaciers and that the opening of the Tasmanian Seaway and the Drake Passage may have aided in the thermal

isolation of the glaciers, but overall, their effects were minimal and, at least in the case of the Drake Passage, delayed a few million years (DeConto and Pollard, 2003).

A growing body of Late Eocene–Early Oligocene data has been obtained from Antarctic, Atlantic, and Equatorial Pacific sites in an attempt to understand the link between climate change and major tectonic events at the Eocene/Oligocene boundary, many of which occurred at high latitudes (Corliss, 1979; Corliss, 1984; Thomas, 1985; Miller et al., 1991; Schroder-Adams, 1992; Thomas, 1992; Zachos et al., 2001; Lear et al., 2004; Coxall et al., 2005). However, minimal work has been done on lower latitude Pacific sites for this boundary. The majority of previous work focused on biostratigraphy or isotopic and geochemical indicators of global environmental change across the E-O transition.

In this study, I examined benthic foraminiferal assemblages across the Eocene-Oligocene climate transition to determine paleoecological change. The shells of benthic foraminifera record oxygen and carbon isotope values of the seawater and conditions at the seafloor. Both surface conditions in the location of bottom water formation and ocean circulation influence their isotopic values. Some species have narrow temperature, salinity, and pH requirements, although conditions do not vary significantly in deep-sea environments (Boardman et al., 1987). Thus, species assemblages of benthic foraminifera indicate environmental conditions at the time of burial, as well as recording $\partial^{18}O$ values of bottom water (Thomas, 1985, 1992, 2000; Boardman et al., 1987; Sen Gupta and Machain-Castillo, 1993).

Results from this study will address: 1) the taxonomic composition of benthic foraminiferal communities and determine if there is any paleoecological and paleoenvironmental change in the communities related to the Eocene-Oligocene climate transition; and 2) attempt to define where Oi-1 occurs in the core samples and see if the foraminiferal communities respond to this event, which is believed to represent the actual initiation and stabilization of ice sheets on Antarctica.

SITE LOCALITIES

ODP Leg 198 – Shatsky Rise

ODP Sites 1209 and 1211 on Shatsky Rise (Figure 1) recovered a nearly continuous record of calcareous sediments across the Eocene/Oligocene boundary. Their location on a topographic high increases the chances for good calcium carbonate shell preservation. The calcite compensation depth (CCD), the depth at which the rate of calcium carbonate formation equals the rates of calcium carbonate dissolution, deepened dramatically everywhere at the E-O climate transition and is indicated by a change in color of the sediment from tan calcareous nannofossil ooze to white calcareous nannofossil ooze (Bralower et al., 2001; Coxall et al., 2005; Hancock et al., 2005). Shipboard analysis during Leg 198 indicated moderate preservation at the late Eocene boundary and moderate to good preservation for the early Oligocene foraminifera (Bralower, Premoli-Silva, et al., 2003).

ODP Site 1209

ODP Site 1209 (Figure 1) is located in the center of the main topographic high of Shatsky Rise, at a mid-bathyal water depth of 2387 m (Bralower et al., 2001). Hole 1209A is located at 32°39.1001'N, 158°30.3560'E. The upper Eocene and lower Oligocene sediments extend from 114.68 to 139.69 meters below seafloor (mbsf). Upper Eocene sediment consists of a finely grained, light brown to tan nannofossil ooze; this ooze is present throughout the entire Eocene section. Lower Oligocene sediment

marks a change to finely grained, light gray to white nannofossil ooze. Foraminiferal preservation was noted as moderate to good at this transition (Bralower et al., 2001).

ODP Site 1211

ODP Site 1211 (Figure 1) is located on the southern section of the southern high at Shatsky Rise, at a lower bathyal water depth of 2907 m (Bralower et al., 2001). Hole 1211A is located at 32°0.1300'N, 157°50.9999'E. The upper Eocene and lower Oligocene sediments at Hole 1211A extend from 71.28 to 90.00 mbsf; as in Hole 1209A, there is a gradual transition from tan nannofossil ooze in upper Eocene sediment to a white nannofossil ooze in lower Oligocene sediment. Foraminiferal preservation was indicated as moderate to good (Bralower et al., 2001).

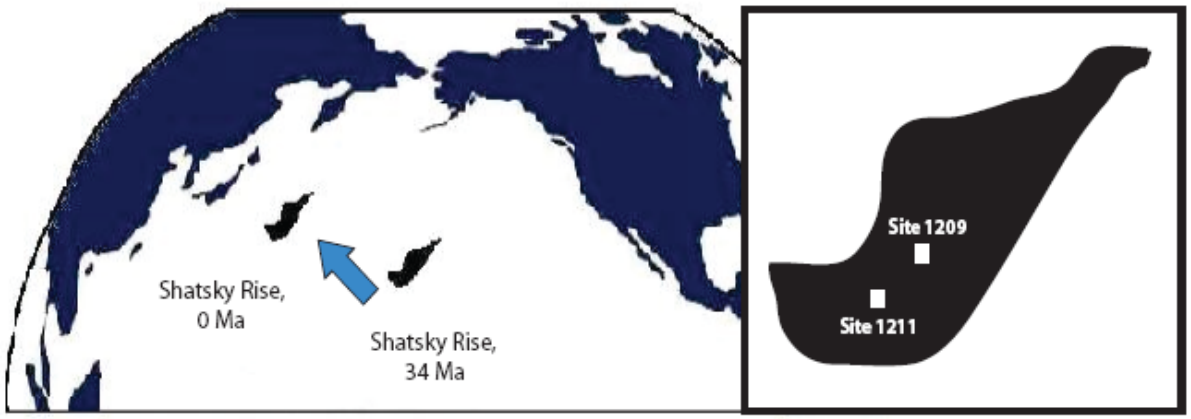

Figure 1. Map of the Northern Pacific Ocean, showing the current and the Eocene/Oligocene position of Shatsky Rise. Inset shows the approximate location of the sites where the samples were taken from (modified from Bralower et al., 2001).

METHODS

Sample Preparation

65 core samples were obtained from two cores from the Integrated Ocean Drilling Program (IODP), with priority given to the sediment located at, above, and below the E/O Boundary. The approximate location of the E/O boundary was determined by the last occurrence of the planktonic foraminifera *Hantkenina spp*. Thirty-four samples were taken from Hole 1209A cores (Figure 2) and thirty-one samples were taken from Hole 1211A cores (Figure 3). Twenty-six of the thirty-four samples from Hole 1209A were taken at 50 cm intervals across the boundary, while the remaining eight were taken at 1.5 m intervals. Twenty-six of the thirty-two samples from Hole 1211A were taken at 50 cm intervals across the boundary, while the remaining six samples were taken at 1.5 m intervals.

Each bulk sample (approximately 10 cm^3) was disaggregated and washed using buffered, de-ionized water (pH 10) and a sodium metaphosphate solution, and placed in a shaker table to aide in the separation of the clay particles from the organisms. Once the samples were clean, they were washed over a 63 μm sieve and then oven dried. All foraminifera were picked using a binocular microscope and placed on a slide for identification and population counts. Complete tests (with an intact aperture) of different species were placed on an SEM stub to be photographed by the JEOL JSM-6400 scanning electron microscope for identification. Once the specimens were

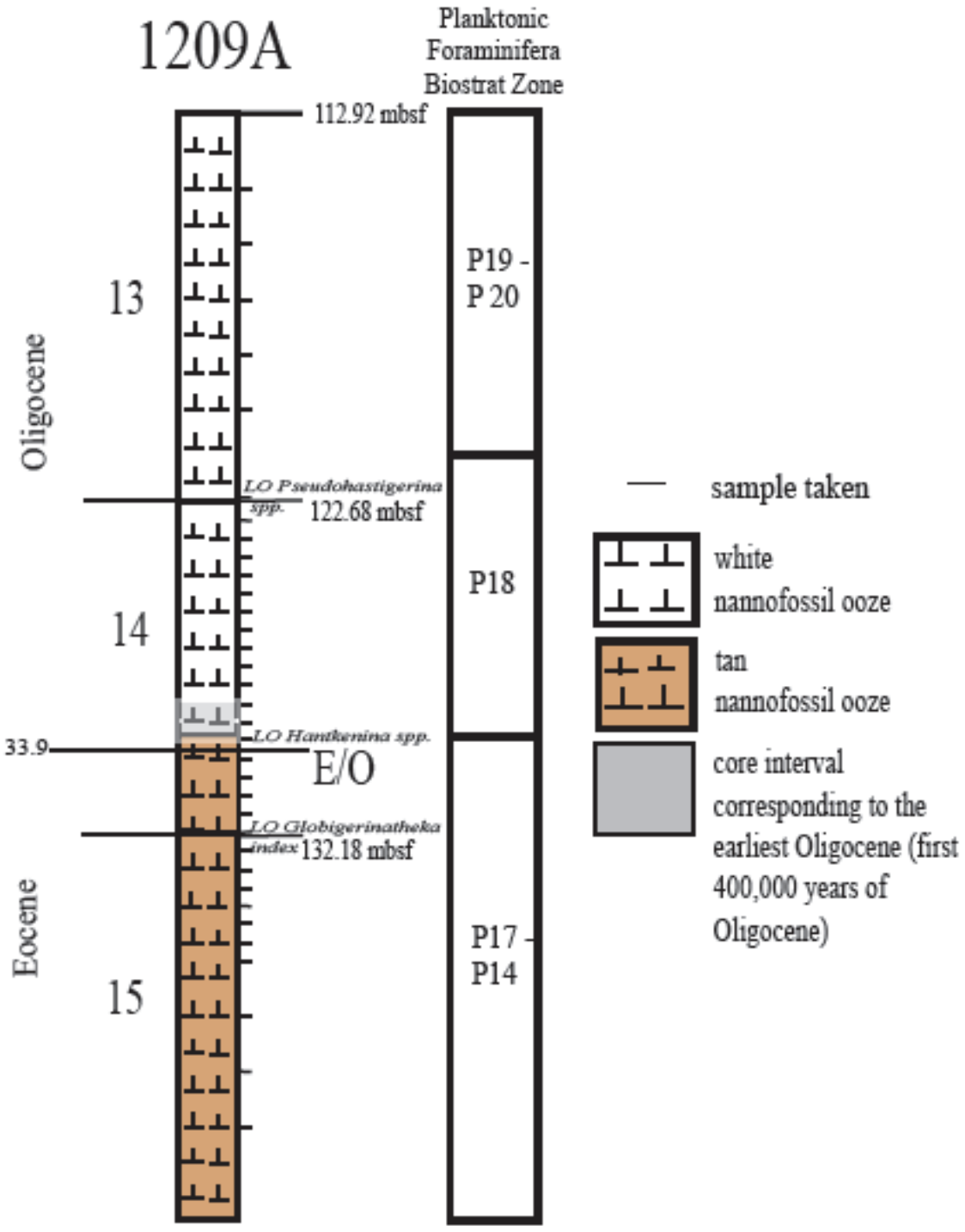

Figure 2. Stratigraphic section for Hole 1209A. Tick marks indicating where samples were taken. At Hole 1209A, 50 cm corresponds to 130,000 years.

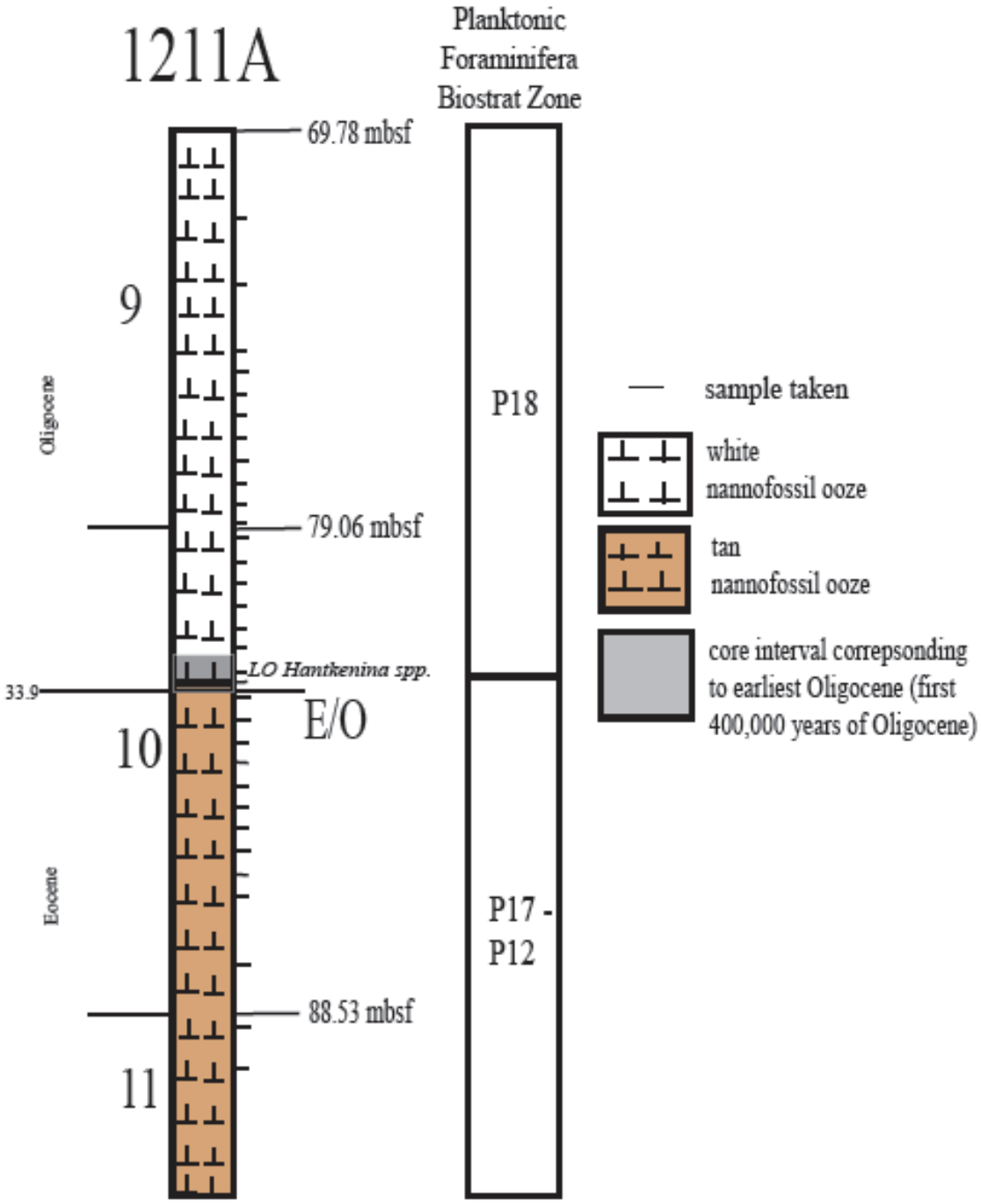

Figure 3. Stratigraphic section for Hole 1211A. Tick marks indicating where samples were taken. At Hole 1211A, 50 cm corresponds to 200,000 years.

identified, proportional abundances were calculated by dividing the abundances of individual species by the standard sample size of 300 (Thomas, 1992). In these samples, a species is considered common if it occurs in abundances of at least 5%.

Age Model

I determined the age model for the Eocene-Oligocene transition section at Holes 1209A and 1211A using published planktonic foraminifera and calcareous nannofossil biostratigraphic data, benthic foraminifera species distributions recognized in this study, sedimentation rates, and isotopic data.

1) The approximate location of the E-O transition was determined by the last occurrence (LO) of the planktonic foraminifera *Hantkenina spp*. Oi-1 was constrained at Hole 1209A by the LO of planktonic foraminifera *Pseudohastigerina spp*. at a depth of 122.17 mbsf, corresponding to 32.0 Ma, and *Globigerinatheka index* at a depth of 131.22 mbsf, corresponding to an age of 34.3 Ma; at Hole 1211A, Oi-1 was constrained by the LO of *Globigerinatheka index* at 88.24 mbsf (34.3 Ma) and by the LO of the calcareous nannofossil *Ericsonia subdisticha* at 78.9 mbsf (33.3 Ma) (Bralower et al., 2001).

2) I was able to confirm the approximate location of the E-O transition in Hole 1209A by the last appearance of *Nuttalides truempyi* between 129.64 and 129.16 mbsf and determined the approximate location of the E-O transition in Site 1211 between 82.54 and 82.09 mbsf. *N. truempyi* was identified by Thomas (1985) as a potential biostratigraphic indicator.

3) I used the sedimentation rate defined by the shipboard party to determine the approximate numerical value for the Late Eocene, the E/O boundary, and the Early Oligocene. The samples from Hole 1209A span 36.55 Ma to 29.92 Ma (Table 1), with 50 cm equal to a time range of 130,000 years, whereas the samples from Site 1211A span 37.00 Ma to 29.40 Ma, with 50 cm corresponding to a time range of 200,000 years (Table 2). The approximate age range is calculated by linearly interpolating between points of known age.

Statistical Analysis

I analyzed samples from Holes 1209A and 1211A separately to preserve any individual site patterns. Samples were analyzed for population assemblages using non-metric multidimensional analysis (NMDS) and correspondence analysis (CA). NMDS is a useful ordination technique because it determines similarity in gradients of either the species or the sites (McCune and Grace, 2002). NMDS is beneficial because it does not assume a linear relationship among the variables, the use of ranked distances will linearize relationships between species space and environmental space, and it allows for any distance measure or relativization to be used for analysis (McCune and Grace, 2002).

Correspondence analysis is an eigenvector method that also indicates similarities in sites and species. Correspondence analysis produces a simultaneous ordination of both rows and columns of a data matrix; this ordination indicates a relationship between the species and the environmental stress (McCune et al., 2002). Species or sites that

Table 1. Table for Hole 1209A, indicating the core section depths, the total depth (mbsf), calculated age (Ma), and dry mass (in grams) sampled.

1209A depths	mbsf	age (Ma)	mass (g)
13-2: 48-50	114.68	29.92	7.630
13-3: 48-50	116.18	30.31	7.910
13-4: 47-49	117.67	30.70	7.300
13-5: 48-50	119.18	31.09	7.270
13-6: 48-50	120.68	31.48	9.490
13-7: 78-80	121.96	31.87	7.480
14-1: 148-150	123.64	32.39	6.420
14-2: 48-50	124.18	32.52	5.270
14-2: 98-100	124.66	32.65	5.930
14-2: 148-150	125.14	32.78	9.210
14-3: 48-50	125.68	32.91	7.810
14-3: 98-100	126.16	33.04	10.340
14-3: 148-150	126.64	33.17	10.660
14-4: 48-50	127.18	33.30	10.860
14-4: 96-98	127.64	33.43	8.720
14-4: 148-150	128.14	33.56	8.360
14-5: 48-50	128.68	33.69	8.630
14-5: 98-100	129.16	33.82	7.810
14-5: 148-150	129.64	33.95	6.840
14-6: 48-50	130.18	34.08	8.170
14-6: 102-104	130.70	34.21	8.800
14-6: 140-141	131.06	34.34	5.100
15-1: 48-50	132.18	34.60	7.940
15-1: 95-97	132.63	34.73	9.190
15-1: 148-150	133.14	34.86	8.500
15-2: 48-50	133.68	34.99	8.360
15-2: 90-92	134.08	35.12	8.470
15-2: 148-150	134.64	35.25	8.600
15-3: 50-52	135.20	35.38	5.460
15-4: 48-50	136.68	35.77	11.000
15-5: 48-50	138.18	36.16	10.030
15-6: 49-51	139.69	36.55	5.040

Table 2. Table for Hole 1211A indicating the core section depths, the total depth (mbsf), calculated age (Ma), and dry mass (in grams) sampled.

1211A depths	mbsf	age (Ma)	mass (g)
9-1: 48-50	69.78	28.80	8.340
9-2: 48-50	71.28	29.40	7.180
9-3: 48-50	72.78	30.00	8.400
9-4: 48-50	74.28	30.60	6.640
9-5: 44-46	75.74	31.20	8.660
9-6: 45-47	77.25	31.80	8.160
10-1: 26-28	79.06	32.60	8.300
10-1: 74-76	79.52	32.80	8.250
10-1: 124-126	80.00	33.00	7.050
10-2: 22-24	80.52	33.20	4.420
10-2: 77-79	81.05	33.40	4.750
10-2: 126-128	81.52	33.60	8.340
10-3: 29-31	82.09	33.80	9.380
10-3: 76-78	82.54	34.00	5.490
10-3: 118-120	82.94	34.20	6.110
10-4: 27-29	83.57	34.40	4.760
10-4: 78-80	84.06	34.60	7.930
10-4: 130-132	84.56	34.80	7.570
10-5: 26-28	84.56	35.00	4.540
10-5: 80-82	85.08	35.20	9.270
10-5: 130-132	85.56	35.40	8.120
10-6: 25-27	86.55	35.60	8.840
10-6: 74-76	87.02	35.80	8.850
10-7: 25-27	87.55	36.00	6.770
11-1: 23-24	88.53	36.40	5.250
11-2: 20-22	90.00	37.00	7.030

cluster together in the ordinations indicate a greater similarity, while those species or sites that plot farther apart are not similar, which indicates there is some different environmental factor separating either the species or plots. No down-weighting or rescaling was needed for the analysis of either the Site 1209 or Site 1211 data matrices.

RESULTS

Late Eocene Biostratigraphy (37-33.9 Ma)

The overall diversity in benthic foraminifera recognized in the Late Eocene Hole 1209A core samples is 30 species, slightly lower than the diversity counts produced at the Equatorial Pacific (DSDP Sites 573, 574, and 575) spanning across the Eocene/Oligocene boundary (Thomas, 1985). The Late Eocene core depths are dominated by *Anomalinoides alazanensis*, *Bulimina aculeata*, *Bulimina alazanensis*, *Globocassidulina subglosa*, *Nuttalides truempyi*, *Oridosalis umbonatus*, *Pleurostomella alternans*, *Siphonodosaria abyssorum*, and *Stilostomella consobrina. Nuttalides truempyi* is more abundant in the early Late Eocene, and declines in abundance until it disappears around the boundary. Notable rare occurrences of species in Late Eocene samples are *Guttalina sp*., which occurs sporadically throughout the core depths, and *Ellipsonodosaria decurta*, which occurs in only one core depth from the Late Eocene (Table 3).

Hole 1211A Late Eocene samples produced an average species diversity of 32 species. *Nuttalides truempyi* is the most dominant species of the Late Eocene, occurring in all but four Late Eocene samples with abundance greater than 10%; this is the highest, most consistent species abundance throughout the entire site. *Nuttalides truempyi* has its highest abundance of 21% in the latest Eocene, right before the boundary, before disappearing in the Oligocene. *Globocassidulina subglosa* reaches it highest abundance, 23%, right before the boundary. *Anomalinoides alazanensis*, *Bolivina huneerii*,

Bulimina alazanensis, *Globocassidulina subglosa*, *Oridosalis umbonatus*, *Pleurostomella alternans*, and *Siphonodosaria abyssorum* are also major components of the Late Eocene foraminiferal assemblages (Table 4).

Earliest Oligocene Biostratigraphy (33.9-33.4 Ma)

Three samples taken from the interval corresponding to the earliest Oligocene possibly span the Oi-1 event. The average benthic foraminiferal diversity for the period spanning 33.9-33.4 Ma at Hole 1209A was 30 species, slightly lower than in the Equatorial Pacific (Thomas, 1985). Both *Bulimina aculeata* and *Bulimina alazanensis* have slightly higher abundances compared to the Late Eocene, while *Bulimina jarvisi* fluctuates from either being present in large abundances or absent throughout this period. The abundance of *Globocassidulina subglosa* decreases to less than 10%, but it remains a prevalent species. *Oridosalis umbonatus*, *Pleurostomella alternans*, *Siphonodosaria abyssorum*, and *Stilostomella consobrina* also decrease in abundance at this transition period (Table 3). With the exception of *Nuttalides truempyi*, no major benthic foraminiferal extinction occurs to correspond with the Eocene-Oligocene climate transition at Hole 1209A; nor is there a major species that acts as a biostratigraphic indicator for Oi-1. In contrast, the high occurrence of rare species at these depths, such as *Lagena auriculata*, *Protobulimina sp.A*, and *Fursenkonia pauciloculata*, may mark this transition.

The species diversity for the earliest Oligocene at Hole 1211A was 32.45 species for the entire section. *Anomalinoides alazanensis*, *Bulimina aculeata*, *Bulimina*

Table 3. 1209A Biostratigraphic chart. Species that in bold occur in high abundances in that multivariate group.

Late Eocene	earliest Oligocene	Early Oligocene I	Early Oligocene II	Early Oligocene III
Bulimina alazanensis	*Bulimina alazanensis*	*Bulimina alazanensis*	*Bulimina alazanensis*	*Bulimina alazanensis*
Bulimina aculeata	*Bulimina aculeata*	*Bulimina aculeata*	*Bulimina aculeata*	*Bulimina aculeata*
Globocassidulina subglosa	***Globocassidulina subglosa***	***Globocassidulina subglosa***	***Globocassidulina subglosa***	
Stilostomella subspinosa	***Stilostomella subspinosa***	*Stilostomella subspinosa*	***Stilostomella subspinosa***	
Bulimina jarvisi	*Bulimina jarvisi*		*Bulimina jarvisi*	*Bulimina jarvisi*
Cibicidoides pseudogenera			***Cibicidoides pseudogenera***	*Cibicidoides pseudogenera*
Pleurostomella alternans	*Pleurostomella alternans*		***Pleurostomella alternans***	***Pleurostomella alternans***
Oridosalis umbonatus		*Oridosalis umbonatus*	***Oridosalis umbonatus***	***Oridosalis umbonatus***
Nuttalides truempyi				
	Nuttalides umbonifera	*Nuttalides umbonifera*	*Nuttalides umbonifera*	***Nuttalides umbonifera***
Cibicidoides mundulus		*Cibicidoides mundulus*		*Cibicidoides mundulus*
Anomalinoides alazanensis		*Anomalinoides alazanensis*		
			Bolivina huneerii	
				Cassidulina sp. A
		Lagena sulcata		
			Nonion havanensis	***Nonion havanensis***
		Pleurostomella obtusa	*Pleurostomella obtusa*	
Pullenia quinqueloba				
		Pullenia salisburyii		
Siphonodosaria abyssorum	***Siphonodosaria abyssorum***			***Siphonodosaria abyssorum***
Siphonodosaria subspinosa				
			Stilostomella abyssorum	
Stilostomella consobrina	*Stilostomella consobrina*		***Stilostomella consobrina***	

Table 4. 1211A Biostratigraphic Chart. Species that occur in bold have high abundance peaks in that multivariate group.

Late Eocene	earliest Oligocene	Early Oligocene I	Early Oligocene II	Early Oligocene III
Globocassidulina subglosa	***Globocassidulina subglosa***	***Globocassidulina subglosa***	***Globocassidulina subglosa***	***Globocassidulina subglosa***
Bulimina alazanensis	***Bulimina alazanensis***	*Bulimina alazanensis*	***Bulimina alazanensis***	*Bulimina alazanensis*
Bolivina huneerii	*Bolivina huneerii*	***Bolivina huneerii***	*Bolivina huneerii*	***Bolivina huneerii***
Cibicidoides mundulus	***Cibicidoides mundulus***	*Cibicidoides mundulus*	*Cibicidoides mundulus*	*Cibicidoides mundulus*
Pleurostomella alternans	***Pleurostomella alternans***	*Pleurostomella alternans*	***Pleurostomella alternans***	***Pleurostomella alternans***
Oridosalis umbonatus		***Oridosalis umbonatus***	***Oridosalis umbonatus***	*Oridosalis umbonatus*
Anomalinoides alazanensis	***Anomalinoides alazanensis***		***Anomalinoides alazanensis***	*Anomalinoides alazanensis*
Bulimina aculeata				
Cibicidoides mollis				
Cibicidoides pseudogenera				
Nuttalides truempyi				
	Nuttalides umbonifera	***Nuttalides umbonifera***	*Nuttalides umbonifera*	***Nuttalides umbonifera***
		Bulimina jarvisi		*Bulimina jarvisi*
		Lagena sulcata		
			Nonion havanensis	
			Pleurostomella obtusa	*Pleurostomella obtusa*
Siphonodosaria abyssorum	*Siphonodosaria abyssorum*			
Siphonodosaria subspinosa				
Stilostomella consobrina	***Stilostomella consobrina***			
			Stilostomella subspinosa	

alazanensis, *Cibicidoides kullenbergi*, *Cibicidoides mundulus*, *Pleurostomella alternans*, and *Stilostomella consobrina* are also major species (Table 4). Again, with the exception of *Nuttalides truempyi*, there is no major benthic foraminiferal extinction at Hole 1211A that corresponds to the Eocene/Oligocene transition, as well as no distinct individual occurring at the proposed Oi-1 marker.

Early Oligocene Biostratigraphy (33.4-29.92 Ma)

The average number of species for the Early Oligocene was 31.25, lower than that of the Equatorial Pacific (Thomas, 1985). For the most part, *Bulimina* species show a general decline in abundance in the Early Oligocene, with a few exceptions at approximately 31 Ma, where their abundance increases to around 10%. With the exception of an abundance peak at 32 Ma, *Globocassidulina subglosa* decreases as the Oligocene progresses. *Nonion havanensis* increases in abundance in the Early Oligocene to become a key component in the assemblage, while *Nuttalides truempyi*, which has a last occurrence at the E/O transition, is replaced by *Nuttalides umbonifera*. *Oridosalis umbonatus* also decreases in abundance with a few abundance spikes in the late Early Oligocene. *Pleurostomella alternans*, *Siphonodosaria abyssorum*, and *Stilostomella consobrina* display similar abundance decreases as *Oridosalis umbonatus* (Table 3). There are many rare species in the Early Oligocene, particularly in the latest Early Oligocene, which draw out relationships and may influence these samples; most notable of these rare occurrences is the lone appearance of *Cassidulina spinosa* with an

abundance of 0.6% at depth 114.68 mbsf (30.50 Ma) and *Ellipsonodosaria decurta* with occurrences of 1% or less at 116.18 mbsf, 122.68 mbsf, and 124.18 mbsf.

The average species diversity for the Early Oligocene core depths at Hole 1211A was 32.5 species. There is no dominant species, as has been the case in the previous core depths. *Bolivina huneerii*, *Globocassidulina subglosa*, *Oridosalis umbonatus*, and *Pleurostomella alternans* are the dominant species, while common species are *Bulimina aculeata*, *Bulimina alazanensis*, *Cibicidoides mundulus*, and *Nonion havanensis*, and *Bulimina aculeata*, *Bulimina alazanensis*, and *Nonion havanensis* have significant spikes near the end of the Early Oligocene depths (Table 4).

Taxa Common to All Intervals

The following taxa occur frequently across the Eocene/Oligocene boundary at both Holes 1209A and 1211A: *Anomalinoides alazanensis, Bolivina huneerii*, *Bulimina aculeata*, *Bulimina alazanensis, Cibicidoides mundulus, Cibicidoides pseudogenerina, Dentalina mucronata, Globocassidulina subglosa, Gyroidinoides lamarckiansis, Gyroidinoides planulatus, Lagena auriculata, Lagena sulcata, Nodosaria sp.A, Nuttalides umbonifera, Oridosalis umbonatus, Pleurostomella alternans, Pleurostomella brevis, Pullenia salisburyi, Pullenia subcarinata, Siphonodosaria abyssorum, Stilostomella consobrina*, and *Stilostomella subspinosa*. Within samples, their individual abundances range from rare to common. Many common species that occur in the Eocene also occur in the Oligocene. However, minor abundance changes in species

such as *Bulimina jarvisi*, *Bolivina huneerii*, and *Pullenia spp*. may indicate potential changes in the bottom water communities.

Hole 1209A Correspondence Analysis

A correspondence analysis of all samples distinguishes four age intervals: the Late Eocene-earliest Oligocene and three successively younger groups in the Early Oligocene. Most Late Eocene core depths, ranging from 139.69 to 129.64 mbsf, and corresponding to ages of 36.55 Ma to 33.95 Ma, plot low on Axis 1 and 2 (Figure 4, Appendix A). The three latest Eocene samples corresponding to depths of 130.18, 129.65, 129.16 mbsf (34.08-33.9 Ma) plot higher on axes 1 than all other Late Eocene samples. The earliest Oligocene group consists of three core depth samples (128.68, 128.14, and 127.64 mbsf), corresponding to ages of 33.82 Ma, 33.69 Ma, and 33.56 Ma. These samples, which may have accumulated during Oi-1 (33.9 - 33.5 Ma), plot close to the three latest Eocene samples on Axes 1 and 2 (Figure 4).

Three species, *Stilostomella subspinosa, Bulimina alazanensis,* and *Globocassidulina subglosa,* reach abundances of 15 - 20% in Late Eocene and earliest Oligocene samples, causing these samples to plot together. Of the three, *Stilostomella subspinosa* and *Bulimina alazanensis* achieve peak abundances in the Late Eocene, although both of these species occur throughout the Early Oligocene in lower abundances. The third, *Globocassidulina subglosa,* occurs frequently throughout the core, reaching peak abundances in the Late Eocene and earliest Oligocene.

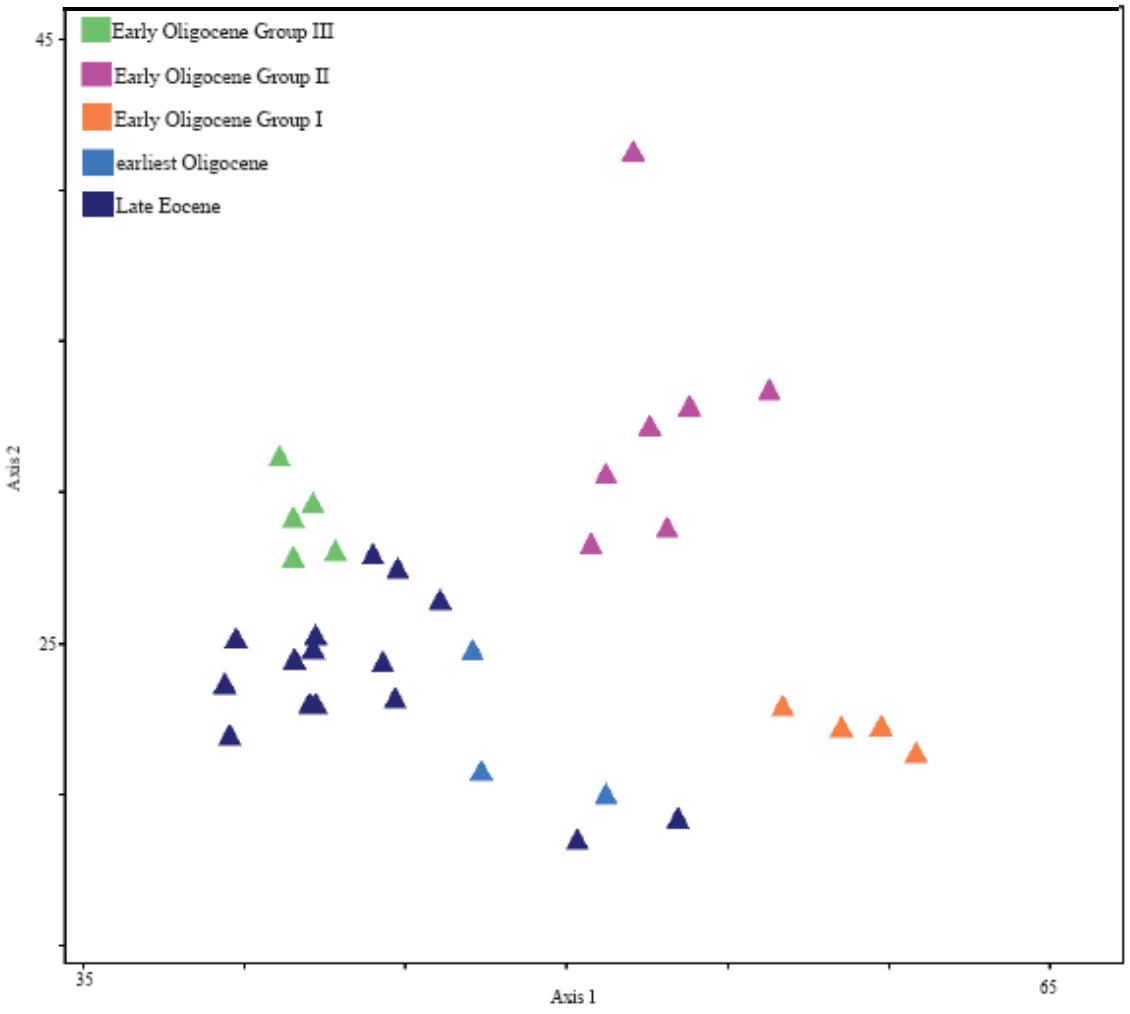

Figure 4. 1209A Correspondence analysis plot showing Axis 1 versus Axis 2. 48% of the information is returned on these two axes; the inertia for the sites was 1.5074 and 1.5972 for the species. The dark blue group corresponding to the Late Eocene depths, consists of core depths 15-6:48-50 to 14-5: 98-100. The light blue group, the earliest Oligocene, consists of core depths 14-5:48-50 to 14-4: 98-100. The orange group contains core depths 14-4:48-50 to 14-3: 48-30, while the purple group contains core depths 14-2: 148-150 to 13-7: 78-80. The green group corresponding to Early Oligocene Group III, contains the core depths 13-6: 48-50 to 13-2: 48-50.

Nuttalides truempyi, identified as a Late Eocene biostratigraphic indicator by Corliss (1981) and Thomas (1985), is the only commonly occurring taxon confined to the Late Eocene at Site 1209A; its occurrence in the Late Eocene samples causes them to plot together. The species *Anomalinoides alazanensis* reaches abundances of 15% in Late Eocene samples, although it occurs throughout the Early Oligocene at much lower abundances. Other species that occur most commonly in Late Eocene samples from Site 1209A include: *Stilostomella consobrina*, *Cibicidoides mundulus*, and *Siphonodosaria subspinosa*. Along with *Nuttalides truempyi*, these species contribute to the separation of Late Eocene samples in the correspondence analysis results.

Bulimina aculeata and *Bulimina jarvisi* characterize earliest Oligocene samples. *Bulimina jarvisi* reaches its highest abundance (22%) in earliest Oligocene samples from 1209A. *Bulimina aculeata* reaches it second highest abundance (10%) in the last earliest Oligocene sample. The second most abundant taxa in all earliest Oligocene samples are *Bulimina alazanensis* and *Stilostomella subspinosa* at 16%. *Bulimina alazanensis* is also quite common (14-16%) in the three latest Eocene samples, which intermingle with Oi-1 samples in the Correspondence Analysis results, and probably contributes to the close linkage between latest Eocene and earliest Oligocene samples in this analysis.

Early Oligocene Group I consists of samples from the core depths 127.64 to 125.68 mbsf, corresponding to an age range of 33.43 Ma to 32.91 Ma and plots furthest away on Axes 1 and 2 (Figure 4). *Pleurostomella obtusa* only occurs in these four depths. *Globocassidulina subglosa* has its highest abundance (27%) in Early Oligocene Groups I and II. Other species characterizing Early Oligocene Group I are *Bulimina*

aculeata, *Bulimina alazanensis*, *Nuttalides umbonifera*, and *Pullenia salisburyii*, all of which reach abundances above 10% in these samples.

Early Oligocene Group II consists of samples from the core depths 125.14 to 121.96 mbsf, corresponding to an age range of 32.78Ma to 31.87Ma (Figure 4). Because these samples have similar species occurrences to those in the Late Eocene, they plot in the middle of Axis 1 high on Axis 2. *Bolivina huneerii, Pleurostomella alternans* and *Nonion havanensis* reach peak abundances in Early Oligocene Group II. Of these, *Bolivina huneerii* and *Pleurostomella alternans* also have abundance peaks the Late Eocene, which may account for the links between Early Oligocene Group II and Late Eocene samples. Two species that peak in the Late Eocene and earliest Oligocene, *Bulimina alazanensis* and *Bulimina jarvisi,* reach abundances of greater than 10% in Early Oligocene Group II.

Early Oligocene Group III consists of the samples from core depths that range from 120.68 to 114.68 mbsf (31.70 Ma to 30.50 Ma) and plot above the Late Eocene samples on the correspondence analysis results for Axes 1 and 3 (Figure 5). *Nuttalides umbonifera* and *Cassidulina spp*. reach peak abundances in Oligocene Group III (*Nuttalides umbonifera*: 15-27%; *Cassidulina spp*: 11%). Increases in the abundance of this taxon have been used an indicator for the Early Oligocene. At Shatsky Rise, the abundance of *Nuttalides umbonifera* appears to increase well after the Eocene/Oligocene boundary, in Early Oligocene Group III samples (31.5-29.9 Ma)*., Bulimina jarvisi,* which also characterizes earliest Oligocene samples, reaches abundances of 16% in Early Oligocene Group III.

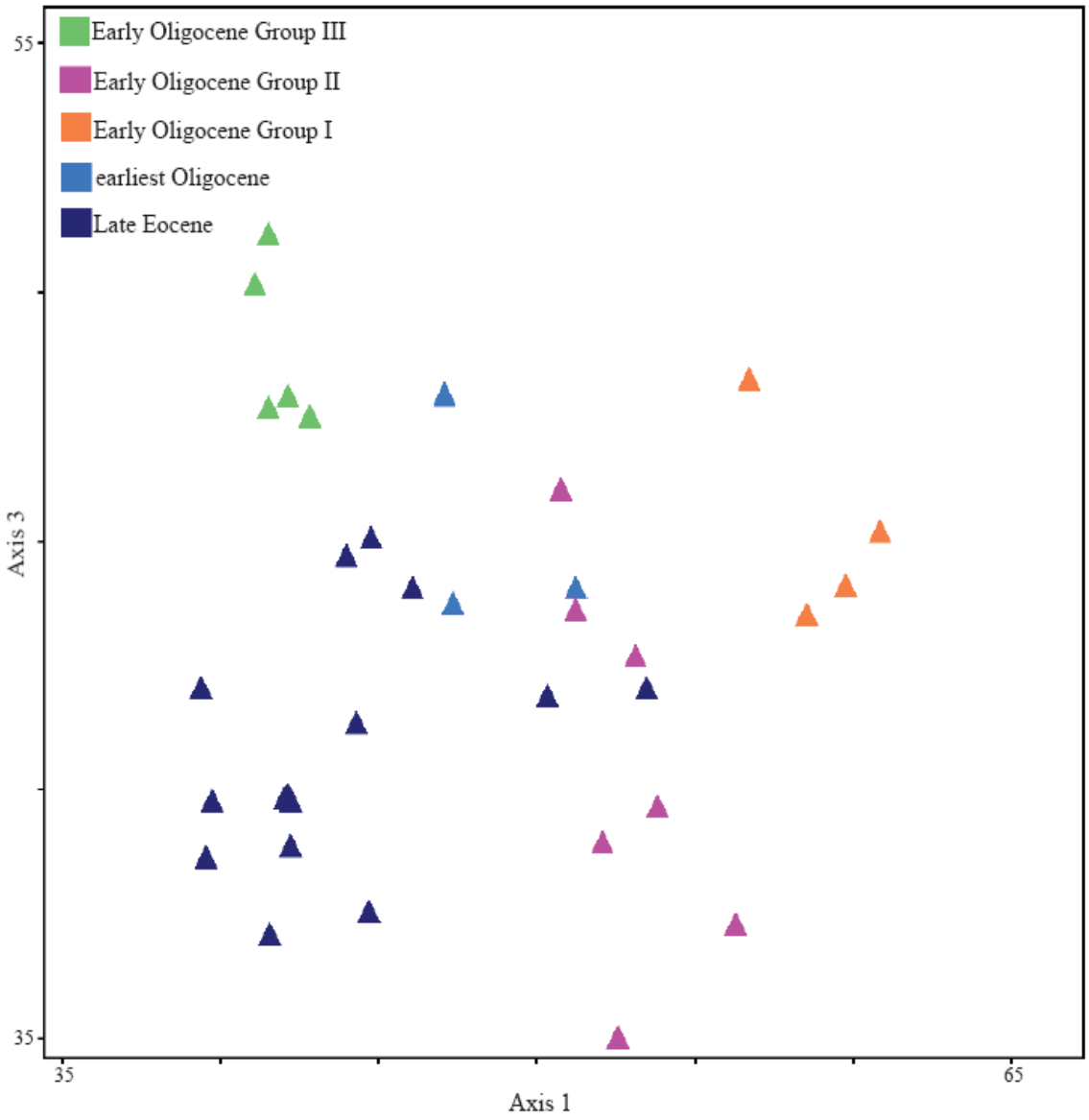

Figure 5. 1209A Correspondence analysis plot showing Axis 1 versus Axis 3. 36% of the information is returned on these two axes. The dark blue group corresponding to the Late Eocene depths, consists of core depths 15-6:48-50 to 14-5: 98-100. The light blue group, the earliest Oligocene, consists of core depths 14-5:48-50 to 14-4: 98-100. The orange group contains core depths 14-4:48-50 to 14-3: 48-30, while the purple group contains core depths 14-2: 148-150 to 13-7: 78-80. The green group corresponding to Early Oligocene Group III, contains the core depths 13-6: 48-50 to 13-2: 48-50.

Hole 1209A Non-Metric Multidimensional Scaling (NMDS)

For the analysis of samples for Hole 1209A, the Sorenson measure of similarity was utilized. Non-metric multidimensional scaling shows chronological distinction among the samples (Figure 6); the results of the grouping displayed a horseshoe trend connecting the Late Eocene through the latest Early Oligocene. There is some slight variation among a few of the core depths, influenced greatly by the large abundances of certain species that occur at certain depths. *Nuttalides truempyi* is still the most influential species in that it heavily draws out the Eocene core depths. *Bulimina jarvisi* is one of the more dominant species influencing the Early Oligocene groups, as it does not have a consistent pattern of occurrence. *Bulimina alazanensis*, *Nuttalides umbonifera*, and *Oridosalis umbonatus* also affect the Early Oligocene groups. The fact that the samples remain mostly in the same groupings throughout the multivariate statistics suggests little variation across the Eocene-Oligocene transition.

Both the CA and NMDS analysis showed an outlier at core depth 14-2: 48-50 cm (corresponding to a depth of 124.18 mbsf and an age of approximately 32.5 Ma). When this site was removed, the pattern of the both the RA and NMDS was disrupted, showing that this samples strongly influences the analysis. This depth, 14-2: 48-50, is an outlier because it contains significant percentages of *Bulimina jarvisi* (18%) and *Pleurostomella alternans* (15%), two species that do not co-occur in this abundance in other 1209A samples..

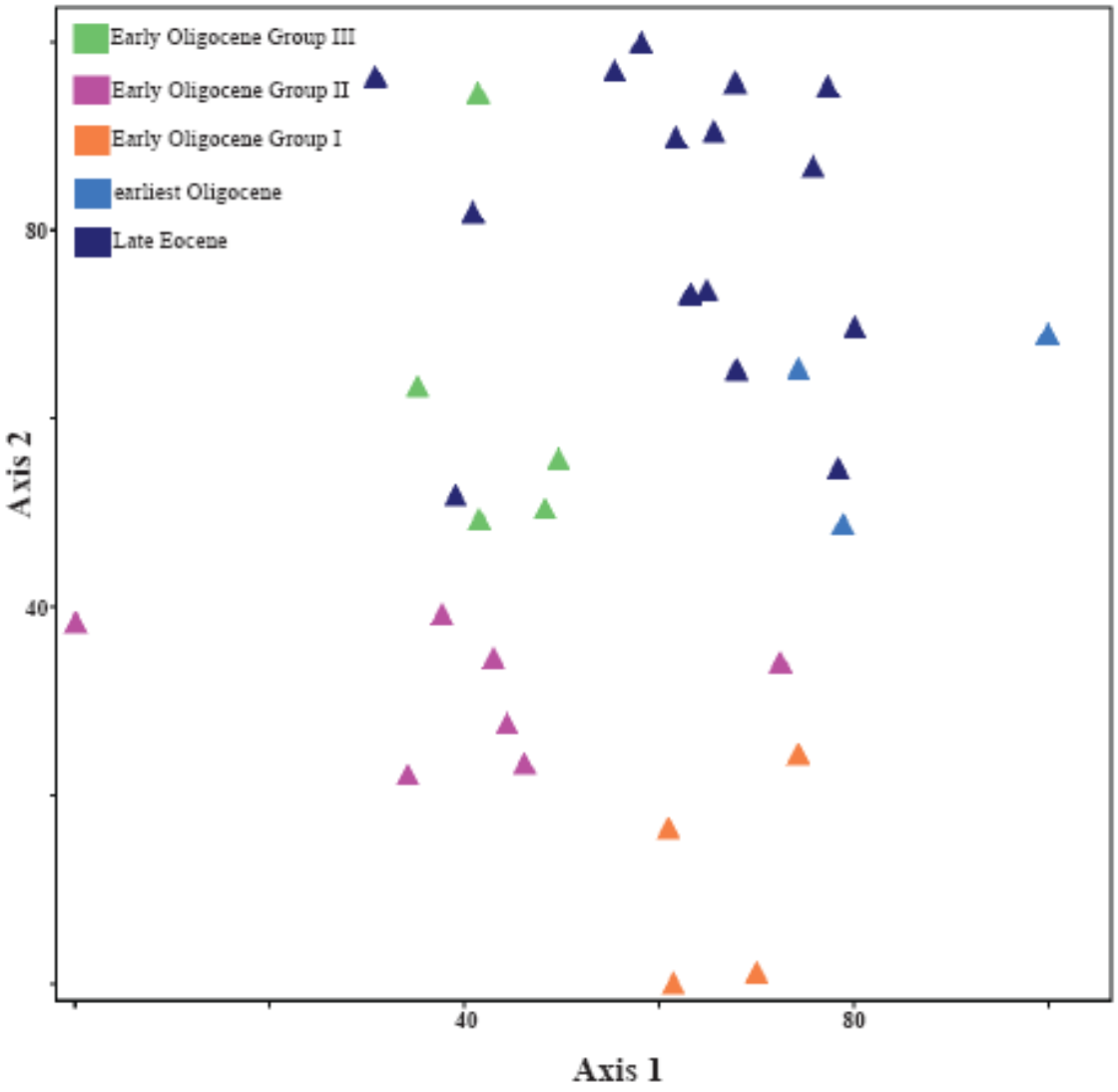

Figure 6. 1209A Non-metric multidimensional scaling plot. The relative stress for this analysis was 17.23 for three dimensions for the sites and 18.75 for the species on three axes. The dark blue group corresponding to the Late Eocene depths, consists of core depths 15-6:48-50 to 14-5: 98-100. The light blue group, the earliest Oligocene, consists of core depths 14-5:48-50 to 14-4: 98-100. The orange group contains core depths 14-4:48-50 to 14-3: 48-30, while the purple group contains core depths 14-2: 148-150 to 13-7: 78-80. The green

Hole 1211A Correspondence Analysis

Correspondence analysis for Site 1211A indicates the separation between the Late Eocene-earliest Oligocene and the Early Oligocene depths. The samples were color-coded as in Site 1209A in order to indicate similarities. The Late Eocene group ranges from 90 to 82.54 mbsf, corresponding to ages of 37-33.8 Ma (Figure 7); these depths plot high on Axis 1 and in the middle of Axis 2. *Nuttalides truempyi* is the most distinct species that appears to be influencing the Late Eocene depths by reaching abundances of 21% close to the Eocene/Oligocene boundary and then disappearing. *Bulimina alazanensis* reaches abundance of 16% and 18% in lower Late Eocene sediments, further characterizing this group. *Globocassidulina subglosa* reaches its highest abundance (23%) in the last Late Eocene sample, but continues to be a dominant species throughout the Early Oligocene. However, *Anomalinoides alazanensis*, *Bolivina huneerii*, *Cibicidoides pseudogenera*, *Oridosalis umbonatus*, and *Pleurostomella alternans* also have an influence on the Late Eocene depths by consistently reaching abundances of greater than 9%. *Pleurostomella alternans* is more dominant in the earlier Late Eocene samples and declines in abundance prior to the Eocene/Oligocene boundary.

The earliest Oligocene core depths, ranging from 82.09 to 80.52 mbsf corresponding to approximate ages of 33.8-33.2 Ma, plot in the middle of Axes 1 and 2 (Figure 7). *Bulimina alazanensis* and *Cibicidoides mundulus* have high abundances in both the Late Eocene depths and the earliest Oligocene depths; causing these

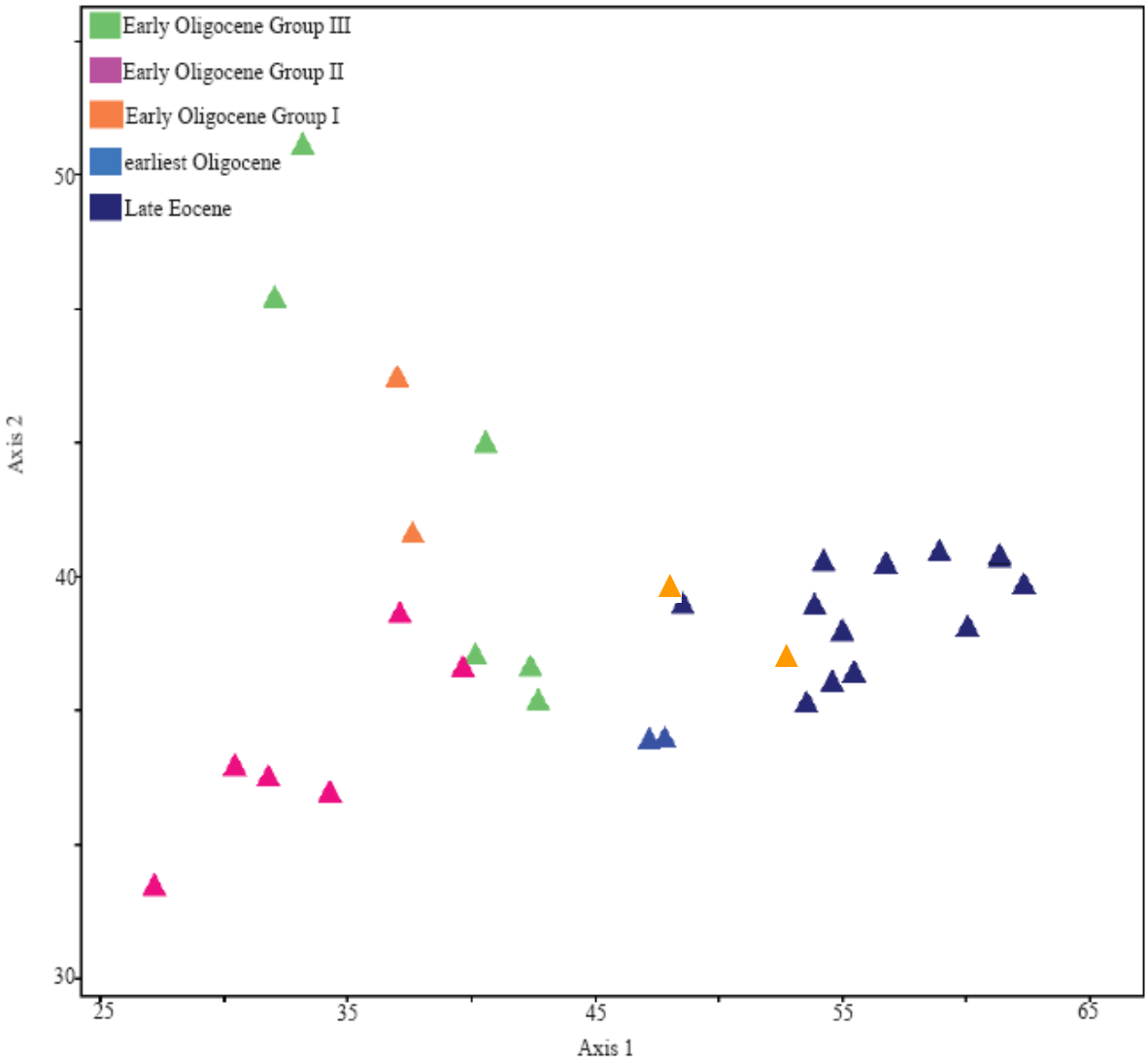

Figure 7. 1211A Correspondence analysis plot. 43% of the information was returned on three axes; the inertia was 0.9966 for the sites and 1.0540 for the species. The dark blue group represents the Late Eocene group, consisting of core depths 11-2:20-22 to 10-3:76-78. The light blue represents the earliest Oligocene group, corresponding to depths 10-3: 29-31 to 10-2: 22-24. The orange grouping corresponds to Early Oligocene Group I, which consists of depths 10-1: 124-126 and 10-1: 74-76. The purple group corresponds to Early Oligocene Group II, consisting of depths 10-1: 26-28 to 9-5: 97-99, while the green group corresponds to Early Oligocene Group III, containing depths 9-5: 44-46 to 9-2: 48-50.

earliest Oligocene samples to plot close to Late Eocene samples. The species *Globocassidulina subglosa*, *Pleurostomella alternans*, and *Stilostomella consobrina* also characterize this group of samples, reaching abundances between 8% and 15%. The similar abundances of *Bulimina alazanensis* and *Pleurostomella alternans* in the Late Eocene and earliest Oligocene samples may cause them to plot close together in the Correspondence Analysis results.

Based on the age model for Hole 1211A, the earliest Oligocene samples that plot close to Late Eocene samples probably accumulated in the first 800,000 years of the Early Oligocene. If so, this group of earliest Oligocene samples includes Oi-1, the first 400,000 years of the Oligocene, and two samples that accumulated immediately after Oi-1 in the Early Oligocene.

Site 1211A Early Oligocene Group I is determined based on the sedimentation rates and the approximate age model; these samples correspond to the four core depths, 80 and 79.52 mbsf, which date to approximately 33.0 and 32.8 Ma (Figure 7). The species *Bolivina huneerii, Bulimina jarvisi, Globocassidulina subglosa, Nuttalides umbonifera,* and *Oridosalis umbonatus* characterize this group by having abundances of 8% in at least one of these samples.

Early Oligocene Group II ranges from depths of 79.06 to 74.75 mbsf that date to approximately 32.6 to 30.8 Ma; these plot low on Axes 1 and 2 (Figure 7). *Pleurostomella alternans* reaches its highest abundance of 18% in this interval, while *Nonion havanensis* reaches 24%, which characterizes this group; the species

Anomalinoides alazanensis, *Oridosalis umbonatus*, and *Stilostomella subspinosa* also heavily influence these depths by having abundances of greater than 8%.

The final group, Early Oligocene Group III, corresponds to the depths 74.28 to 71.28 mbsf that date to approximately date to 30.6 to 29.4 Ma; these samples plot in the middle on Axis 1 and highest on Axis 2 (Figure 7). *Bolivina huneerii* reaches its highest abundance (11%) in the Early Oligocene but is also dominant for the rest of Early Oligocene Group III, *Bulimina jarvisi* reaches its highest abundance of 17% in the later samples of Early Oligocene Group III, while *Globocassidulina subglosa* reaches 18%, and *Nuttalides umbonifera* reaches its highest abundance of 18%. *Globocassidulina subglosa* and *Pleurostomella alternans* also characterize this relationship by reaching abundances greater than 10%.

Hole 1211A Non-Metric Multidimensional Scaling

The Hole 1211A samples were analyzed using the Sorenson metric of similarity. The results of non-metric multidimensional scaling at Site 1211A show similar chronological distinction among the core depths (Figure 8). *Nuttalides truempyi*, which has its last occurrence at the Eocene/Oligocene boundary, distinguishes Late Eocene depths. *Oridosalis umbonatus* influences the early Early Oligocene depths while *Bulimina jarvisi* affects the middle Early Oligocene depths, again because it occurs sporadically throughout the core depths. *Bulimina alazanensis* and *Nuttalides umbonifera* also affect all the Early Oligocene depths.

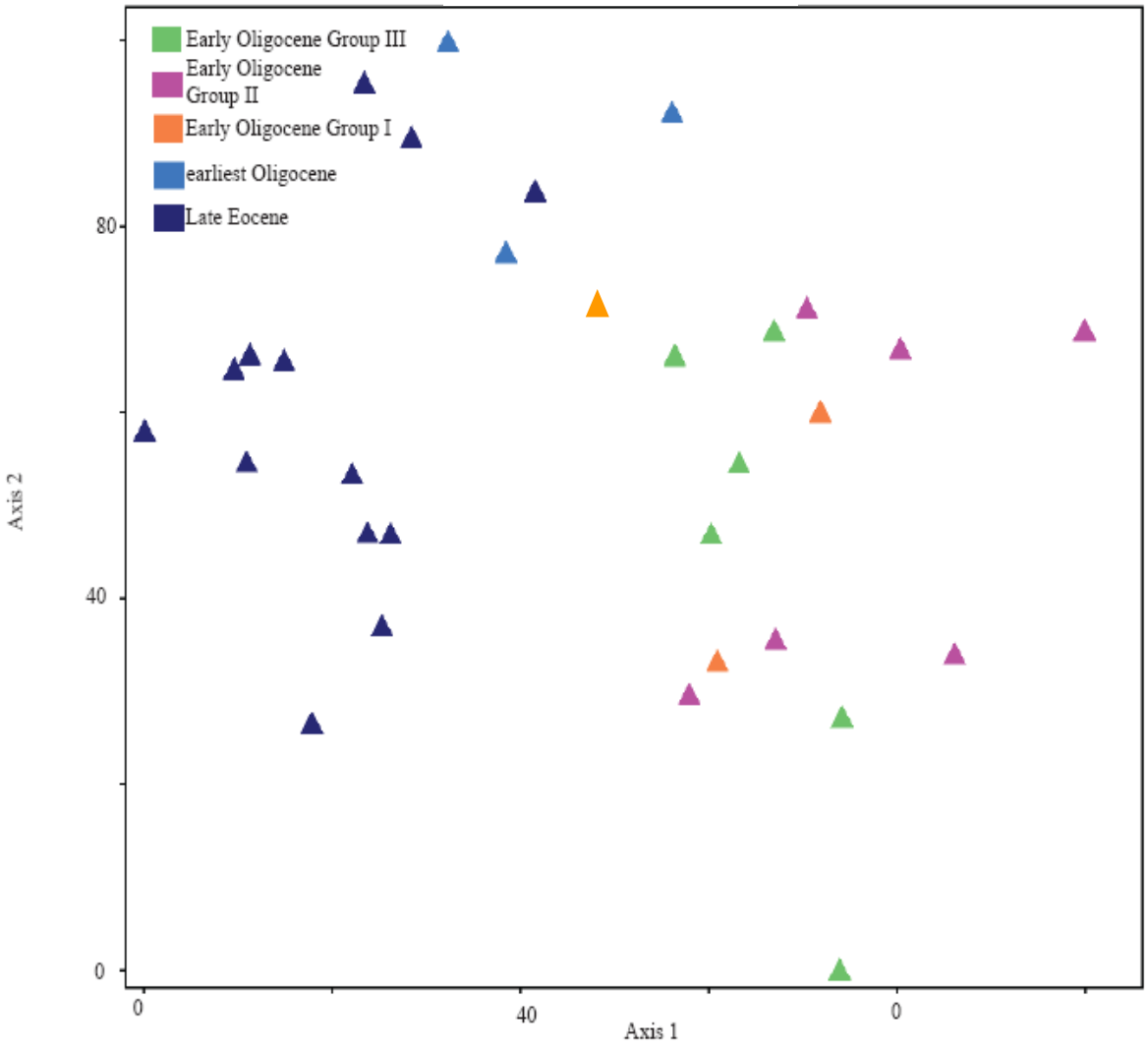

Figure 8. 1211A Non-metric multidimensional scaling plot. The stress produced for the sites was 14.31 and 26.29 for the species. The dark blue group represents the Late Eocene group, consisting of core depths 11-2:20-22 to 10-3:76-78. The light blue represents the earliest Oligocene group, corresponding to depths 10-3: 29-31 to 10-2: 22-24. The orange grouping corresponds to Early Oligocene Group I, which consists of depths 10-1: 124-126 and 10-1: 74-76. The purple group corresponds to Early Oligocene Group II, consisting of depths 10-1: 26-28 to 9-5: 97-99, while the green group corresponds to Early Oligocene Group III, containing depths 9-5: 44-46 to 9-2: 48-50.

Synopsis

1) The last appearance of *Nuttalides truempyi* was at 129.16 mbsf for Site 1209A, and 82.54 mbsf for Site 1211A, indicating that the transition from the Eocene to the Oligocene occurred after this depth (the last occurrence of *Nuttalides truempyi* is thought to be a good indicator for the Eocene/Oligocene transition: Corliss, 1984; Thomas, 1985); the abundance of *Nuttalides umbonifera* increases in the Oligocene, both at the Shatsky Rise (this study) and in the Weddell Sea (Thomas, 1992). However, at Shatsky Rise, *Nuttalides umbonifera* abundances do not rise significantly until Early Oligocene Group III.

2) Common species that occur in both the Eocene and Oligocene samples at both sites are: *Anomalinoides alazanensis*, *Bolivina huneerii*, *Bulimina aculeata*, *Bulimina alazanensis*, *Cibicidoides mundulus*, *Globocassidulina subglosa*, *Nuttalides umbonifera*, *Oridosalis umbonatus*, and *Pleurostomella alternans*.

3) No oxygen isotope work has been done to date the Eocene/Oligocene boundary and Oi-1 at Shatsky Rise. Using sedimentation rate and the last occurrences of the planktonic foraminifera *Hantkenina sp*. and the calcareous nannofossil *Ericsonia subdisticha*, I constrained the E/O boundary to 122.17 mbsf at Site 1209A and 78.9 mbsf at Site 1211A.

4) There is no major assemblage change, i.e. no major restructuring of the assemblages, across the E/O boundary at either Site 1209A or Site 1211A.

5) The average species richness for Site 1209A was 30.65 species and 32.61 species for Site 1211A. This is lower than that recorded for the Equatorial Pacific (Thomas, 1985) but consistent with those recorded by the shipboard party. A decreasing species-richness gradient between high and low latitudes was identified by Thomas and Gooday (1996), and the Shatsky Rise samples fit in the middle of this gradient.

6) Correspondence Analysis groups core samples based on their faunal composition. Late Eocene and earliest Oligocene samples group closely together. Axes 1 and 2 reveal a stratigraphic gradient from Eocene and earliest Oligocene samples through Early Oligocene Group I, Early Oligocene Group II, and Early Oligocene Group III; axes 1 and 3 resolves the relationships between the Early Oligocene Group I, Early Oligocene Group II, and Early Oligocene Group III samples.

7) Non-metric multidimensional scaling produces the same chronological distinction among the core depths as the reciprocal averaging results.

DISCUSSION

Identifying the Eocene/Oligocene Boundary and Oi-1

The last occurrence of *Nuttalides truempyi* at or just before the Eocene/Oligocene boundary has proven a useful stratigraphic indicator in the Equatorial Pacific, the Southern Pacific, and the Antarctic (Thomas, 1985; Corliss et al., 1984; Thomas, 1992). Based on the last occurrences of *Nuttalides truempyi* at Shatsky Rise, the E/O boundary lies between 129.16 mbsf and 128.56 mbsf at Site 1209A, and between 82.54 mbsf and 82.09 mbsf at Site 1211A. Although I can identify the approximate location of the Eocene/Oligocene boundary for Site 1209A and Site 1211A at Shatsky Rise based on *Nuttalides truempyi*, there is no major restructuring of the benthic foraminiferal assemblages at the boundary.

Oi-1 is the oxygen isotope excursion that began at the E/O boundary and continued approximately 400,000 years into the Oligocene (Miller et al., 1991; Lear et al., 2000; Zachos et al., 2001; Lear et al., 2004; Coxall et al., 2005); at this transition, there is an enrichment of 1.6‰ in the $\delta^{18}O$ composition of benthic foraminifera (Zachos et al., 2001). The approximate location of Oi-1 was identified using the sedimentation rates presented in the preliminary report of Leg 198, and biostratigraphic data from planktonic foraminifera and calcareous nannofossils (Bralower, Premoli-Silva, et al., 2001). No oxygen isotope data exist for the Eocene-Oligocene transition from the Shatsky Rise. Based on sedimentation rates, the end of Oi-1 is approximately located

between 128.14 mbsf and 127.64 mbsf at Site 1209A, and 81.52 mbsf and 81.05 mbsf at Site 1211A.

Interpreting Environmental Change Across the Eocene/Oligocene Boundary and Oi-1

Interpretations of isotopic shifts across the Eocene/Oligocene boundary and Oi-1 vary. Oi-1 may indicate the initiation of rapid and significant glaciation on Antarctica (Lear et al., 2000; Zachos et al., 2001; Wade and Pälike, 2004; Coxall et al., 2005; Pälike et al., 2006). Coxall et al. (2005) believed that the Oi-1 shift in oxygen isotopes was too large to be accounted for by ice build-up in the Southern Hemisphere, and suggested that ice accumulation in both the Northern and the Southern Hemispheres occurred at this time. The extinction of *Hantkenina sp*. at the Eocene/Oligocene boundary has been used as a biostratigraphic indicator (Gradstein, Ogg, and Smith, 2004), and a general dwarfing in *Paragloborotalia* occurring after Oi-1 was attributed to environmental stress by Wade et al. (2007). Because *Hantkenina* and other planktonic foraminifera began to decline in the Late Eocene, Wade et al. (2007) suggested that global cooling began in the Late Eocene and continued across the boundary, and that significant glaciation began at the end of Oi-1, at 33.5 Ma.

Paleoecology

The multivariate results show no large break in assemblage composition at the Eocene/Oligocene boundary. Instead, the major ecological reorganization occurs in the early Oligocene, between Late Eocene-earliest Oligocene samples and the rest of the

Early Oligocene samples (Early Oligocene Groups I, II, and III). It seems that the environment of benthic foraminiferal communities during the earliest Oligocene was most similar to that of the Late Eocene.

Thomas and Gooday (1996) examined oceanic productivity in the Cenozoic and noted that food supply is an important control on the distribution of benthic foraminifera. In the Middle Eocene, benthic foraminifera (i.e. *Epistominella exigua* and *Alabaminella weddellensis*) feeding on phytodetritus, i.e. phytoplankton, sourced in upwelling zones, appeared for the first time. Thomas and Gooday (1996) also noted a decrease in high-latitude faunal diversity in the Late Eocene, which resulted in a species-richness gradient between high and low latitudes, from to 15-30 species for Southern Polar sites to 40-50 species in equatorial Pacific sites. They attributed this gradient to a decrease of organic matter deposition caused by increased bottom water oxygenation or by increased seasonality at high latitudes (Thomas and Gooday, 1996).

Thomas et al. (2000) identified three benthic foraminiferal assemblages that characterize modern oceans and suggested a Late Eocene origin for these assemblages: 1) relatively eutrophic faunas with high percentages of infaunal taxa such as *Bolivina*, *Bulimina*, and *Pullenia*; 2) faunas containing the 'phytodetritus' species *Epistominella exigua* and *Alabaminella weddellensis,* which appear adapted to open-ocean oligotrophic environments with seasonal pulses of phytodetritus; and 3) faunas in open-ocean, oligotrophic, corrosive waters, dominated by *Nuttalides umbonifera*. The main differences between the Late Eocene and early Paleogene faunas are the absence of 'phytodetritus species' from most areas except the Weddell Sea, and the presence of

assemblages dominated by cylindrical taxa (Thomas and Gooday, 1996; Thomas et al., 2000).

In the Late Eocene, the faunas from Shatsky Rise are dominated by *Bolivina* and *Bulimina*, which was the first fauna identified by Thomas et al. (2000). These eutrophic species decline in abundance through the Early Oligocene, but do have brief abundance peaks in Early Oligocene Group II and III. At Shatsky Rise, Early Oligocene Group III is dominated by *Nuttalides umbonifera*, possibly indicating a corrosive bottom water environment. The switch from buliminid-bolivinid dominance to *Nuttalides umbonifera* dominance from the Late Eocene-earliest Oligocene to the Early Oligocene is consistent with an increase in the oxygen content of bottom waters at Shatsky Rise across this interval. No 'phytodetritus' species were identified at Shatsky Rise, nor would such species be expected in middle of an ocean basin in the mid-latitudes.

Samples from Shatsky Rise are intermediate in their species diversity and composition compared to the high latitude and equatorial Pacific sites examined by Thomas and Gooday (1996). Diversity levels are similar to high latitude sites; however, Late Eocene and Early Oligocene samples from the southern high latitudes contain abundant phytodetritivore species, which are absent in samples from Shatsky Rise. In the Late Eocene, Southern polar sites apparently had seasonally high nutrient pulses (Thomas and Gooday, 1996).

Because *Nuttalides truempyi* only occurred in Late Eocene samples, it is the lone species significantly influencing the Late Eocene cluster produced by Correspondence Analysis (CA) and Non-metric Multidimensional Scaling (NMDS). Thomas et al.

(2000) reviewed possible explanations for the extinction of *Nuttalides truempyi* and the increased abundance of *Nuttalides umbonifera* in the early Oligocene, including: intensification of Antarctic Bottom Water, increased corrosivity of bottom waters, and extreme oligotrophy. However, increased corrosivity of bottom water may not have been tied to increased oxygen contents across the Eocene-Oligocene climatic transition at Shatsky Rise.

At Shatsky Rise, Late Eocene samples have an abundance of *Bulimina* species, which have been associated with low oxygen environments (Sen Gupta and Machain-Castillo, 1993; Thomas and Gooday, 1996). Although the Late Eocene was a time of global cooling (Prothero, 1994; Lear et al., 2000; Zachos et al., 2001; Lear et al., 2004; Coxall et al., 2005; Eldrett et al., 2007), ocean bottom water temperatures in the Late Eocene were warmer than in the Early Oligocene. The abundance of low-oxygen species in Late Eocene deep ocean environments is consistent with the idea that slower ocean circulation and low oxygen availability on the ocean bottom are correlated with warm temperatures. At Shatsky Rise during the earliest Oligocene, *Bulimina* abundances decrease slightly, indicating a change to a more oxygen-rich environment as the intensification of thermo-haline circulation brought deep-water masses having higher levels of oxygen to the Pacific Ocean.

Bulimina abundances continue to decline throughout the rest of the Early Oligocene, indicating ever increasing oxygen content in the deep ocean. Increasing oxygen supply to the deep ocean is consistent with colder climate and glaciation in Antarctica, which would send cold water having high oxygen content to the bottom of

the ocean (Trujillo and Thurman, 2005). While peaks in the abundance of *Bulimina*, most notably in *B. jarvisi* and sometimes *B. aculeata* and *B. alazanensis*, occur throughout the Early Oligocene, there is no continuity or pattern to the peaks; which may indicate brief returns to low-oxygen conditions. Most *Bulimina* peaks occur in Early Oligocene I and II samples; few occur in Early Oligocene III samples, which lay near the end of the Early Oligocene. It is important to note that buliminids do not completely disappear in the Early Oligocene of Shatsky Rise, as they did in the Weddell Sea (Thomas, 1992) and the Kerguelen Plateau (Schroder-Adams, 1991). The persistence of buliminids at Shatsky Rise suggests lower oxygen environments in the Pacific Ocean than in the Southern Ocean (Weddell Sea and Kerguelen Plateau) at the Eocene/Oligocene transition.

The low abundance of *Pullenia* in the Oligocene of Shatsky Rise also supports the hypothesis of rising oxygen levels. *Pullenia*, in general, inhabit low oxygen environments (Thomas, 2004). In the Early Oligocene of Shatsky Rise, *Pullenia* species very rarely have an average abundance exceeding 5%; the one high occurrence of *Pullenia salisburyi* (15%) occurs with the highest abundance of *Bulimina aculeata* (12%) at Site 1209A. This brief peak indicates the Early Oligocene was not continuously well-oxygenated, suggesting brief returns to Late Eocene 'low-oxygen' conditions. In general, however, the Oligocene benthic environments of Shatsky Rise were more oxygenated than the Eocene. This substantiates the claim that deep-water masses started to form and brought well-oxygenated waters from the North Atlantic by the Eocene/Oligocene transition (Keigwin, 1980).

Many of the taxa that are present in the Late Eocene and Early Oligocene at Shatsky Rise are cosmopolitan, making it difficult to assign environmental preferences (Poag, 1981; Murray, 1991). *Nuttalides truempyi*, the only abundant species confined to the Late Eocene, may have been adapted to low oxygen or low nutrient conditions. Thomas et al. (2000) viewed *N. truempyi* as a relatively oliogtrophic. *Siphonodosaria abyssorum*, *Stilostomella consobrina*, and *Stilostomella subspinosa,* which have their highest abundances in Late Eocene samples, but persist into the Early Oligocene, may have had oxygen or nutrient requirements similar to the buliminds (Kaiho, 1992). The abundance distribution of these three species at Shatsky Rise supports this observation.

At Shatsky Rise, there are even fewer species confined to the Early Oligocene than the Late Eocene. *Pleurostomella obtusa* reaches its highest abundances in Early Oligocene Group I, during the period of significant ice formation. *Pleurostomella alternans*, while present in all but one sample, reaches its highest abundances in Early Oligocene Group II, indicating the ability to survive well in colder temperatures.

These findings are consistent with those of Corliss et al. (1984) and Thomas (1985, 1992) for Eocene to Oligocene benthic foraminiferal assemblages from the Atlantic, Indian, and Pacific Oceans. In a global analysis of benthic foraminiferal assemblages from the Late Eocene and Early Oligocene, Corliss observed only minor changes in foraminiferal assemblage composition across the boundary. Only one species associated with cold Antarctic bottom water, *Epistominella umbonifera*, was significantly affected at this time (Corliss, 1981). *Epistominella umbonifera* was not recovered from the Shatsky Rise samples reported here.

Corliss suggested that the wide environmental tolerances of latest Eocene and earliest Oligocene foraminifera, as indicated by the majority of cosmopolitan genera such as *Cibicidoides*, *Oridosalis*, *Globocassidulina*, and *Nuttalides*, accounted for the minor faunal changes observed at this boundary. Corliss reported a 0.76‰ change in $\delta^{18}O$ across the Eocene/Oligocene boundary, corresponding to a temperature change of 3°C or less. The observed faunal change may have been a result of bottom-water temperature change and not the build-up of ice on Antarctica (Corliss, 1981). Moreover, faunal changes recorded from the Middle to Late Eocene suggest gradual formation of the psychrosphere (deep cold bottom water) at this time as opposed to at the Eocene/Oligocene boundary (Corliss, 1979).

Thomas (1985) analyzed benthic foraminiferal assemblages from the central equatorial Pacific Ocean and also noted that in general, the assemblages did not change significantly across the Eocene/Oligocene boundary. She did find the last occurrence of *Nuttalides truempyi* at the Eocene/Oligocene boundary, making it a good biostratigraphic marker for the boundary. The abundance of *Nuttalides umbonifera* was not as great in the Pacific as in the Atlantic Ocean at this time; nonetheless, the abundance of *N. umbonifera* increased to fill the niche left by the disappearance of *Nuttalides truempyi* (Thomas, 1992). In general, the Late Eocene/earliest Oligocene taxa of the Equatorial Pacific were very cosmopolitan, indicating the wide environmental tolerances of the constituent species of the assemblages, which were dominated by *Globocassidulina subglosa, Oridosalis umbonatus,* and *Gyroidinoides spp.* (Thomas, 1985).

A separate study showed that the dominance in the taxonomic composition of Late Eocene and Oligocene benthic foraminiferal assemblages of the Weddell Sea in the Antarctic gradually changed in three distinct steps, from *Bulimina* to *Turrilina* to *Nuttalides* as the climate cooled and the magnitude of the Antarctic currents increased (Thomas, 1992). These assemblage changes were initiated in the Late Eocene, shortly before the E/O boundary, and continued after Oi-1, into the Early Oligocene. The lack of major change in Equatorial Pacific assemblages and gradual change in Weddell Sea assemblages, contradicts initial reports of the boundary as containing major extinctions for benthic foraminifera (Prothero, 1994).

CONCLUSIONS

A gradual decline in temperatures throughout the Eocene culminates in a significant decrease in temperature and an increase in $\partial^{18}O$ composition at the Eocene/Oligocene boundary. The cooling climate may have contributed to the glaciation of Antarctica that continued throughout the Early Oligocene and in turn, increased glaciation of Antarctica may have contributed to Late Eocene and Early Oligocene cooling (Zachos et al, 1992; Lear et al., 2000; Zachos et al., 2001; Lear et al., 2004; Coxall et al., 2005; Pälike et al., 2006; Eldrett et al., 2007). Recent theories have suggested that the build-up of glaciers did not occur until 400,000 years after the Eocene/Oligocene boundary, at the end of another isotopic shift identified as Oi-1 (Miller et al., 1991; Lear et al., 2000; Zachos et al., 2001; Lear et al., 2004; Coxall et al., 2005; Pälike et al., 2006). The record of climate and environmental change in the deep ocean derives primarily from benthic foraminifera, which record shifts in oxygen isotopes in their calcium carbonate tests. Paleoecological analysis of benthic foraminiferal species assemblages can be a useful indicator of paleoenvironmental conditions such as temperature, salinity, and pH (Boardman et al., 1987; Sen Gupta and Machain-Castillo, 1993).

Benthic foraminiferal assemblages from Shatsky Rise across the Eocene/Oligocene transition do not show an extinction event at the boundary, nor do any major new taxa appear in the Early Oligocene. There are many cosmopolitan species that survive and persist through the Eocene-Oligocene transition, but there are also some

individual species that suggest changes in the benthic environment. *Bulimina* species thrive in the Late Eocene, with a minimal decline in abundance across the boundary; *Bulimina* abundances continued to decline in the Early Oligocene, although there are some abundance peaks in the Early Oligocene. This is significant because *Bulimina* species are indicators of low oxygen environments, suggesting Late Eocene bottom waters were low in oxygen, but gradually became more ventilated throughout the Early Oligocene, with some intervals of poor ventilation indicated by abundance peaks of buliminids and *Pullenia* in the Early Oligocene. The transition from *Nuttalides truempyi* dominated assemblages in the Late Eocene to *Nuttalides umbonifera* dominated assemblages in the Early Oligocene suggests an increase in deep ocean corrosivity.

Multivariate analyses indicate a distinction between Late Eocene and Early Oligocene samples, with earliest Oligocene samples that may have accumulated during the earliest Oligocene, consistently grouping with Late Eocene. This distinction suggests that no major change in bottom water environments occurred at the boundary. Instead, the most significant environmental change in the Late Eocene – Early Oligocene occurred about 400,000 years after the boundary, probably associated with the earliest Oligocene. There are distinct differences in Late Eocene-earliest Oligocene and Early Oligocene benthic environments. My results support an interpretation of cooling temperatures at the Eocene/Oligocene boundary continuing into the Early Oligocene, with ice build-up beginning 400,000 years after the boundary and contributing to the increase in better oxygenated bottom water.

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APPENDIX A

SITE 1209A SPECIES PRESENT AND RAW ABUNDANCES (%)

Core Section	Depth (mbsf)	Approximate Age (Ma)	Multivariate group	*Anomalinoides alazanensis*	*Bolivina huneerii*	*Bulimina aculeata*	*Bulimina alazanensis*	*Bulimina jarvisi*
13-2: 48-50	114.68	29.92		6.91	1.64	5.59	0.33	16.12
13-3: 48-50	116.18	30.31	Early Oligocene Group III	6.64	0.35	4.90	5.94	2.80
13-4: 47-49	117.67	30.70		4.11	7.91	2.22	10.13	0.32
13-5: 48-50	119.18	31.09		3.01	5.02	5.02	11.04	16.39
13-6: 48-50	120.68	31.48		5.96	4.64	7.95	1.99	16.23
13-7: 78-80	121.96	31.87		2.06	2.41	1.72	2.06	12.71
14-1: 48-50	122.68	32.13		1.67	2.00	2.00	1.67	1.00
14-1: 98-100	123.16	32.26	Early Oligocene Group II	0.00	11.56	5.10	3.06	0.00
14-1: 148-150	123.64	32.39		0.00	1.71	8.87	11.95	2.05
14-2: 48-50	124.18	32.52		0.00	8.14	0.51	0.51	18.07
14-2: 98-100	124.66	32.65		0.67	0.67	0.33	0.00	0.00
14-2: 148-150	125.14	32.78		2.33	1.00	0.67	0.33	0.67
14-3: 48-50	125.68	32.91		3.34	1.00	12.04	0.33	0.00
14-3: 98-100	126.16	33.04	Early Oligocene Group I	5.15	0.34	3.09	0.69	0.00
14-3: 148-150	126.64	33.17		4.30	2.98	6.62	10.60	0.00
14-4: 48-50	127.18	33.30		5.21	1.30	4.56	0.98	0.98
14-4: 96-98	127.64	33.43	earliest Oligocene	1.80	0.00	10.07	16.55	0.00
14-4: 148-150	128.14	33.56		1.38	0.34	5.52	7.24	17.93
14-5: 48-50	128.68	33.69		4.88	0.70	6.97	10.45	22.65
14-5: 98-100	129.16	33.82		6.51	0.33	5.86	14.66	0.00
14-5: 148-150	129.64	33.95		3.48	0.35	6.62	16.72	0.00
14-6: 48-50	130.18	34.08		0.00	0.34	8.56	16.44	4.79
14-6: 102-104	130.7	34.21		0.00	0.71	8.19	3.56	0.00
14-6: 140-141	131.06	34.34		14.29	0.00	3.06	1.70	0.68
15-1: 48-50	132.18	34.60		15.44	2.57	1.47	2.21	1.47
15-1: 95-97	132.63	34.73	Late Eocene	5.70	0.00	0.00	9.40	1.01
15-1: 148-150	133.14	34.86		5.59	0.00	0.31	16.46	0.00
15-2: 48-50	133.68	34.99		13.03	0.00	0.33	5.86	2.28
15-2: 90-92	134.08	35.12		3.64	4.64	0.66	2.98	10.93
15-2: 148-150	134.64	35.25		0.00	11.97	6.80	7.12	0.00
15-3: 50-52	135.2	35.38		4.33	8.00	8.00	3.67	3.67
15-4: 48-50	136.68	35.77		5.43	0.96	4.79	7.35	0.00
15-5: 48-50	138.18	36.16		0.64	0.32	0.96	26.37	1.93
15-6: 49-51	139.69	36.55		2.78	0.93	0.31	16.98	0.62

Core Section	*Cassidulina spinosa*	*Cassidulina subglosa*	*Chrysalongonium lamella*	*Cibicidoides kullenbergi*	*Cibicidoides mollis*	*Cibicidoides mundulus*	*Cibicidoides pseudo*	*Dentalina mucronata*	*Ellipsolagena barri*
13-2: 48-50	0.66	0.99	0.00	0.00	1.64	1.32	0.99	0.66	0.00
13-3: 48-50	0.00	11.89	0.35	0.00	1.05	0.35	5.24	0.00	0.70
13-4: 47-49	0.00	0.95	0.32	0.00	0.95	0.00	5.38	0.00	0.00
13-5: 48-50	0.00	5.02	0.00	0.00	0.67	0.00	0.00	0.33	0.00
13-6: 48-50	0.00	3.31	0.00	0.00	0.00	0.00	0.33	0.66	0.00
13-7: 78-80	0.00	4.12	0.00	1.72	0.00	3.44	2.75	1.03	0.00
14-1: 48-50	0.00	0.33	1.33	2.33	3.67	3.00	0.33	1.33	2.33
14-1: 98-100	0.00	0.00	0.00	4.42	3.40	5.10	0.00	0.00	0.68
14-1: 148-150	0.00	0.00	0.00	1.71	1.71	0.00	0.34	3.07	1.71
14-2: 48-50	0.00	0.00	0.00	3.82	0.00	3.05	0.00	1.53	2.04
14-2: 98-100	0.00	0.00	0.00	3.01	0.00	3.68	10.37	1.00	2.68
14-2: 148-150	0.00	0.00	1.67	2.33	3.33	3.00	1.67	3.33	0.00
14-3: 48-50	0.00	0.00	1.00	0.00	0.00	1.67	0.67	0.00	0.00
14-3: 98-100	0.00	0.00	0.69	0.00	0.00	5.15	0.00	0.69	0.00
14-3: 148-150	0.00	0.00	0.00	0.00	0.00	2.32	1.66	0.99	0.00
14-4: 48-50	0.00	0.00	1.30	0.00	1.30	1.30	0.00	0.65	0.00
14-4: 96-98	0.00	0.00	0.72	0.00	2.52	0.00	0.36	0.36	0.00
14-4: 148-150	0.00	0.00	0.34	0.00	0.00	1.03	0.00	0.00	0.00
14-5: 48-50	0.00	0.00	2.44	0.00	1.74	1.05	5.23	0.00	0.00
14-5: 98-100	0.00	0.00	0.65	0.00	0.00	1.63	1.63	1.63	0.00
14-5: 148-150	0.00	0.00	0.00	0.00	0.00	5.23	0.00	0.35	0.00
14-6: 48-50	0.00	1.71	0.34	0.00	1.37	3.77	0.00	0.68	0.68
14-6: 102-104	0.00	1.07	0.00	0.36	1.42	2.49	2.14	0.00	0.00
14-6: 140-141	0.00	3.06	0.00	0.00	1.02	1.36	1.36	0.34	2.04
15-1: 48-50	0.00	5.51	0.37	0.00	2.57	2.94	5.88	0.37	0.00
15-1: 95-97	0.00	1.68	0.34	0.00	3.02	5.37	2.01	0.00	0.00
15-1: 148-150	0.00	0.93	0.00	0.00	1.55	2.17	0.62	0.31	0.00
15-2: 48-50	0.00	1.30	0.33	0.00	1.95	2.93	2.61	0.33	0.00
15-2: 90-92	0.00	0.99	0.00	0.00	1.66	2.32	3.64	0.33	0.00
15-2: 148-150	0.00	0.97	0.00	0.00	2.59	2.59	1.29	1.29	0.00
15-3: 50-52	0.00	0.67	0.00	0.00	2.33	3.00	13.33	1.67	0.00
15-4: 48-50	0.00	0.64	0.00	0.00	2.24	6.39	8.31	0.64	0.00
15-5: 48-50	0.00	2.57	0.00	0.00	2.25	0.00	3.86	0.64	0.00
15-6: 49-51	0.00	0.00	0.00	3.09	3.70	5.56	1.85	0.62	0.00

Core Section	*Ellipsonodosaria decurta*	*Elonsonodosaria sp. A*	*Entosolonia acuta*	*Entosolenia stap*	*Evolvecassidulina sp. A*	*Fursenkonia pauciloculata*	*Glandulina laevigata*	*Globocassidulina subglosa*	*Guttalina lehneri*
13-2: 48-50	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.99	2.30
13-3: 48-50	0.35	0.00	0.00	0.00	0.00	1.05	0.00	1.05	0.00
13-4: 47-49	0.00	2.22	0.00	2.22	0.00	0.63	0.00	0.95	5.70
13-5: 48-50	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	1.34
13-6: 48-50	0.00	3.64	0.00	0.00	0.00	1.32	0.00	1.32	0.99
13-7: 78-80	0.00	0.00	0.00	0.34	0.00	0.00	0.00	10.31	0.34
14-1: 48-50	0.33	0.00	1.00	0.33	0.00	0.00	0.00	8.33	0.33
14-1: 98-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.21	0.00
14-1: 148-150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.29	0.00
14-2: 48-50	1.78	0.00	0.00	0.00	0.00	0.00	0.00	1.27	2.04
14-2: 98-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.06	0.33
14-2: 148-150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.67	0.00
14-3: 48-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.73	0.00
14-3: 98-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.49	0.00
14-3: 148-150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.59	0.00
14-4: 48-50	0.00	0.00	0.65	0.00	0.00	0.00	0.00	6.84	0.00
14-4: 96-98	0.00	0.00	0.36	0.00	0.00	2.88	0.00	3.60	0.00
14-4: 148-150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.45	0.00
14-5: 48-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.27	0.00
14-5: 98-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.45	0.00
14-5: 148-150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.23	0.00
14-6: 48-50	0.00	0.00	0.00	0.00	0.68	0.00	0.00	6.85	0.00
14-6: 102-104	0.00	0.00	0.00	0.00	3.20	0.00	0.36	8.19	0.00
14-6: 140-141	0.34	0.00	0.00	0.00	1.02	2.04	0.00	2.38	1.70
15-1: 48-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.03	0.00
15-1: 95-97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.75	2.01
15-1: 148-150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.39	4.66
15-2: 48-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.89	2.93
15-2: 90-92	0.00	0.00	0.00	0.00	0.00	0.33	0.00	6.95	0.66
15-2: 148-150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.18	1.62
15-3: 50-52	0.00	0.00	0.00	0.00	0.67	0.00	0.00	7.00	4.33
15-4: 48-50	0.00	0.32	0.00	0.00	0.00	0.32	0.00	18.21	3.83
15-5: 48-50	0.00	0.32	0.00	0.00	0.00	0.32	0.00	7.40	2.57
15-6: 49-51	0.00	0.00	0.00	0.00	0.00	0.62	0.00	15.43	0.93

Core Section	*Gyroidinoides grimsdaii*	*Gyroidinoides lamarckiansis*	*Gyroidinoides planulatus*	*Hoeglundia sp. A*	*Karriella bradyi*	*Lagena asperoides*	*Lagena auriculata*	*Lagena sulcata*	*Nodosaria sp.A*
13-2: 48-50	0.66	0.00	0.33	0.33	0.00	0.00	0.00	1.97	0.00
13-3: 48-50	2.80	0.35	0.35	0.00	0.35	0.00	1.75	2.10	0.35
13-4: 47-49	1.90	0.63	0.00	0.95	0.63	0.32	0.00	1.90	0.95
13-5: 48-50	0.00	0.67	0.00	0.33	0.00	0.00	0.00	0.00	0.33
13-6: 48-50	0.00	0.99	0.00	0.66	0.33	0.00	0.66	1.99	0.33
13-7: 78-80	1.37	1.72	0.34	0.34	0.69	0.34	1.03	1.72	0.69
14-1: 48-50	1.00	0.67	1.00	0.00	0.00	0.00	0.00	2.00	1.33
14-1: 98-100	0.00	0.00	0.00	0.68	0.00	0.00	0.34	0.00	1.36
14-1: 148-150	0.00	2.39	0.00	0.00	0.00	2.05	0.34	1.37	5.80
14-2: 48-50	0.00	2.04	0.00	0.00	2.54	0.76	0.00	0.51	2.04
14-2: 98-100	0.00	1.34	0.33	0.00	0.67	0.33	0.00	0.67	4.01
14-2: 148-150	1.00	0.33	0.33	0.00	0.67	0.00	0.00	1.33	0.00
14-3: 48-50	0.33	0.67	0.00	0.33	0.00	2.01	1.34	1.67	0.33
14-3: 98-100	0.34	0.69	0.00	0.69	0.00	2.06	0.34	4.12	1.03
14-3: 148-150	0.66	0.00	0.00	0.66	0.00	1.32	0.00	7.95	2.65
14-4: 48-50	0.00	0.65	0.33	0.33	0.00	0.98	0.65	5.21	1.63
14-4: 96-98	0.00	0.00	0.00	0.36	0.00	0.00	1.08	0.36	0.00
14-4: 148-150	0.00	1.72	0.00	0.00	0.00	1.38	0.69	2.07	3.45
14-5: 48-50	0.70	0.35	0.00	0.00	0.00	0.00	0.35	3.14	2.79
14-5: 98-100	0.33	0.00	0.33	1.30	0.00	2.93	0.33	4.23	1.63
14-5: 148-150	0.35	0.00	0.00	0.35	0.00	3.48	0.70	1.74	2.09
14-6: 48-50	0.34	2.40	0.00	0.34	0.00	0.00	0.68	4.45	1.71
14-6: 102-104	2.49	2.49	0.00	0.36	0.00	0.36	0.36	2.14	2.49
14-6: 140-141	9.86	1.70	1.70	0.68	0.00	0.34	1.02	2.04	3.40
15-1: 48-50	3.68	0.74	0.00	0.00	0.00	0.37	0.00	2.57	2.94
15-1: 95-97	3.36	1.68	0.00	0.00	0.00	0.00	0.00	1.68	0.00
15-1: 148-150	0.00	0.62	0.62	0.00	0.00	1.86	0.00	0.00	2.48
15-2: 48-50	1.63	1.30	0.00	0.33	0.33	0.00	0.65	0.65	1.95
15-2: 90-92	0.33	5.30	0.66	0.00	0.00	0.00	0.00	0.00	1.66
15-2: 148-150	1.62	0.32	0.00	0.00	0.65	0.00	0.00	0.32	1.94
15-3: 50-52	0.67	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.67
15-4: 48-50	0.00	0.96	0.64	0.00	0.00	0.00	0.32	0.32	1.28
15-5: 48-50	0.32	1.29	0.00	0.00	0.00	0.00	0.64	1.29	1.29
15-6: 49-51	1.23	0.62	0.00	0.31	0.00	0.00	0.62	2.16	0.00

Core Section	*Nodosaria sp.B*	*Nogenerina rohri*	*Nonion havanensis*	*Nuttalides truempyi*	*Nuttalides umbonifera*	*Oridosalis umbonatus*	*Pleurostomella alternans*	*Pleurostomella brevis*	*Pleurostomella obtusa*
13-2: 48-50	0.00	2.30	3.95	0.00	24.01	4.61	5.92	0.33	0.00
13-3: 48-50	0.00	0.00	3.50	0.00	15.73	3.50	8.74	1.75	0.00
13-4: 47-49	0.00	0.00	2.85	0.00	5.70	13.92	6.96	1.27	0.00
13-5: 48-50	0.00	1.67	8.36	0.00	27.76	2.68	2.34	0.00	0.00
13-6: 48-50	0.00	1.66	3.31	0.00	19.54	2.65	3.31	4.97	0.00
13-7: 78-80	0.00	0.69	3.44	0.00	5.84	3.78	2.75	0.69	5.15
14-1: 48-50	1.00	1.67	7.33	0.00	6.67	3.67	14.00	2.00	3.33
14-1: 98-100	0.34	0.00	0.00	0.00	0.00	0.00	22.45	1.70	0.00
14-1: 148-150	4.44	0.00	10.24	0.00	1.02	10.92	5.46	2.73	0.68
14-2: 48-50	3.82	0.00	21.63	0.00	1.27	1.78	15.78	1.02	0.00
14-2: 98-100	2.01	0.00	8.36	0.00	0.00	1.34	23.75	1.34	1.34
14-2: 148-150	0.00	0.00	6.67	0.00	6.67	6.33	8.67	1.00	1.00
14-3: 48-50	1.34	0.00	0.00	0.00	5.69	7.69	2.34	2.68	8.70
14-3: 98-100	2.41	0.00	0.00	0.00	9.62	7.90	3.78	3.44	7.90
14-3: 148-150	5.96	0.00	0.00	0.00	5.96	4.97	1.99	1.66	9.60
14-4: 48-50	0.00	0.00	0.65	0.00	12.05	6.51	3.58	1.30	17.26
14-4: 96-98	0.00	0.36	5.04	0.00	0.72	3.24	7.91	1.80	1.80
14-4: 148-150	0.00	0.00	0.00	0.00	12.76	3.10	1.72	0.00	5.17
14-5: 48-50	0.00	0.00	0.00	0.00	7.44	4.88	0.00	0.00	3.48
14-5: 98-100	0.00	0.00	0.00	11.40	3.26	2.61	1.30	1.95	1.63
14-5: 148-150	0.00	1.39	0.00	12.20	1.39	3.48	7.67	0.70	1.05
14-6: 48-50	0.00	1.03	2.40	5.14	3.77	7.88	5.82	0.68	0.34
14-6: 102-104	0.00	1.07	3.91	1.78	11.39	4.63	11.74	0.71	0.00
14-6: 140-141	1.70	0.00	1.70	6.80	1.02	6.12	5.10	0.34	0.68
15-1: 48-50	0.74	0.37	0.74	6.99	0.74	2.94	4.41	0.74	0.00
15-1: 95-97	0.00	0.00	1.01	20.13	0.67	10.74	5.03	0.67	0.00
15-1: 148-150	0.00	0.00	0.93	10.87	0.00	2.80	10.25	1.55	0.00
15-2: 48-50	0.00	0.00	0.65	17.59	0.65	4.89	4.56	1.95	0.00
15-2: 90-92	0.00	0.00	2.32	14.24	0.66	10.93	4.97	1.32	0.00
15-2: 148-150	0.00	0.32	0.32	8.09	1.62	12.62	9.06	1.62	0.00
15-3: 50-52	0.00	0.00	0.00	8.33	1.67	4.67	7.00	2.33	0.00
15-4: 48-50	0.00	0.00	0.00	14.38	1.28	5.75	6.39	0.32	0.32
15-5: 48-50	0.00	0.00	0.00	9.65	1.29	9.97	7.72	2.89	0.00
15-6: 49-51	0.00	1.85	0.00	12.35	1.85	2.47	11.73	0.00	0.00

Core Section	*Protobulimina grata*	*Pullenia bulloides*	*Pullenia quinqueloba*	*Pullenia salisburyi*	*Pullenia subcarinata*	*Pulvulinella mexicanus*	*Robulus occidentalus*	*Robulus plumeri*	*Siphonodosaria abyssorum*
13-2: 48-50	0.33	0.66	0.00	0.00	0.99	0.00	0.66	1.64	8.55
13-3: 48-50	0.00	1.05	1.05	0.70	1.40	2.10	1.05	3.50	0.35
13-4: 47-49	0.00	0.00	1.27	0.32	0.63	2.53	0.95	0.00	0.00
13-5: 48-50	0.00	0.67	0.00	0.00	0.33	0.00	0.00	0.00	0.00
13-6: 48-50	0.00	0.33	0.99	0.33	0.33	0.00	1.66	0.00	0.66
13-7: 78-80	0.00	2.41	1.72	3.09	5.15	0.00	0.00	0.00	0.69
14-1: 48-50	0.33	3.67	1.00	3.67	1.67	0.00	0.33	0.33	1.67
14-1: 98-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
14-1: 148-150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
14-2: 48-50	0.25	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00
14-2: 98-100	0.33	0.00	0.00	0.67	3.01	0.00	0.00	0.00	1.00
14-2: 148-150	0.67	1.33	0.67	5.00	2.33	0.67	0.67	0.33	0.33
14-3: 48-50	0.00	0.00	0.00	15.05	1.00	0.00	0.00	0.00	1.67
14-3: 98-100	1.03	0.00	0.00	7.90	1.03	0.00	0.00	0.34	0.00
14-3: 148-150	0.33	0.00	0.00	5.63	2.98	0.00	0.00	0.66	4.30
14-4: 48-50	0.00	1.30	0.00	5.21	2.61	3.26	0.65	0.00	2.93
14-4: 96-98	0.00	4.32	0.00	0.00	0.00	5.40	0.00	0.00	8.99
14-4: 148-150	0.34	0.00	0.00	1.03	3.10	0.00	0.00	0.00	6.90
14-5: 48-50	0.35	0.00	0.00	0.35	0.00	0.00	0.00	0.00	6.27
14-5: 98-100	0.98	0.00	0.00	5.21	1.95	0.00	0.00	0.00	5.86
14-5: 148-150	0.35	0.00	0.00	2.79	1.74	0.00	0.00	1.39	8.71
14-6: 48-50	0.68	0.00	0.68	0.34	0.00	1.03	0.00	0.00	0.68
14-6: 102-104	0.00	2.49	8.19	0.00	1.78	0.00	0.00	0.00	0.71
14-6: 140-141	0.00	2.38	3.06	0.34	1.70	1.70	0.00	0.00	0.34
15-1: 48-50	0.74	1.10	0.37	0.37	0.00	0.00	0.74	0.37	0.00
15-1: 95-97	0.00	0.34	0.34	0.00	0.67	0.00	1.68	3.36	1.68
15-1: 148-150	0.00	0.62	0.00	0.31	0.00	0.00	0.93	1.24	0.62
15-2: 48-50	0.33	0.00	0.33	0.00	0.33	0.00	2.28	0.00	3.26
15-2: 90-92	0.00	0.00	0.66	0.00	0.99	0.00	3.31	4.97	3.97
15-2: 148-150	0.32	0.00	0.00	0.00	0.00	0.00	1.62	0.00	12.30
15-3: 50-52	0.67	0.00	0.67	0.33	0.00	0.00	0.00	0.00	8.00
15-4: 48-50	0.32	3.83	0.00	0.00	0.32	0.00	0.32	0.00	1.92
15-5: 48-50	0.32	4.50	0.32	0.00	0.00	0.00	0.00	0.00	6.11
15-6: 49-51	1.23	0.00	0.00	0.00	0.00	0.00	3.09	4.63	0.00

Core Section	*Siphonodosaria quadrulata*	*Siphonodosaria spinosa*	*Stilostomella abyssorum*	*Stilostomella consobrina*	*Stilostomella lepidula*	*Stilostomella subspinosa*	*Uvigerina sp.A*	*Vulvulina jarvisi*
13-2: 48-50	0.66	0.00	0.00	0.99	0.00	0.33	0.00	0.00
13-3: 48-50	0.00	0.00	0.00	3.85	0.00	1.05	0.00	0.00
13-4: 47-49	6.33	0.00	0.00	1.27	0.00	2.85	0.00	1.90
13-5: 48-50	0.67	0.00	0.00	0.67	0.00	3.01	0.00	0.67
13-6: 48-50	0.00	3.31	0.00	3.64	0.00	0.00	0.00	0.00
13-7: 78-80	0.00	1.03	2.75	1.72	0.00	2.41	0.00	3.44
14-1: 48-50	1.00	0.00	0.00	5.00	0.00	1.67	0.00	0.67
14-1: 98-100	0.34	0.00	0.00	8.84	0.00	2.38	0.68	0.00
14-1: 148-150	0.68	0.00	0.00	1.37	0.00	0.00	1.37	3.41
14-2: 48-50	0.00	0.00	1.27	0.76	0.00	1.02	0.00	0.25
14-2: 98-100	0.33	0.00	1.00	0.67	0.00	7.69	0.00	0.00
14-2: 148-150	0.00	0.00	7.00	3.67	0.00	4.00	0.00	0.33
14-3: 48-50	0.00	0.00	0.67	2.34	0.00	5.69	0.00	0.67
14-3: 98-100	0.34	0.00	0.00	0.69	0.00	1.03	0.00	0.00
14-3: 148-150	0.00	0.00	0.00	0.33	0.00	1.32	0.00	0.00
14-4: 48-50	0.00	0.00	1.30	3.91	0.00	2.28	0.00	0.33
14-4: 96-98	1.08	0.00	0.00	1.44	0.00	16.19	0.00	0.72
14-4: 148-150	0.00	2.76	0.00	2.41	0.00	1.03	0.00	2.76
14-5: 48-50	0.00	0.00	0.00	6.27	0.00	1.05	0.00	0.00
14-5: 98-100	0.00	0.00	1.30	5.54	0.00	3.26	0.00	0.33
14-5: 148-150	0.00	3.83	0.00	4.53	0.00	2.09	0.00	0.00
14-6: 48-50	0.68	0.00	0.00	4.11	5.82	2.05	0.34	0.34
14-6: 102-104	0.71	0.00	0.00	7.83	0.71	0.00	0.00	0.00
14-6: 140-141	3.40	0.00	0.00	5.78	0.00	0.68	0.00	0.00
15-1: 48-50	0.37	0.37	0.00	10.29	0.00	4.41	0.00	1.10
15-1: 95-97	0.00	0.00	0.00	2.68	0.00	0.34	0.00	0.67
15-1: 148-150	0.00	0.00	0.93	1.24	0.00	17.70	0.00	3.42
15-2: 48-50	0.00	0.00	0.00	5.21	0.00	10.42	0.00	1.95
15-2: 90-92	0.00	0.00	0.00	2.98	0.00	0.66	0.00	0.33
15-2: 148-150	0.00	0.00	0.00	5.83	0.00	0.00	0.00	0.00
15-3: 50-52	0.67	0.00	0.33	0.33	0.00	0.00	0.00	1.67
15-4: 48-50	0.32	0.00	0.32	1.28	0.00	0.00	0.00	0.00
15-5: 48-50	0.64	0.00	0.00	1.61	0.00	0.00	0.00	0.00
15-6: 49-51	0.00	0.00	0.00	2.16	0.00	0.31	0.00	0.00

APPENDIX B

SITE 1211A SPECIES PRESENT AND RAW ABUNDANCES (%)

Core Section	Depth (mbsf)	Approximate Age (Ma)	Multivariate group	*Anomalinoides alazanensis*	*Bolivina huneerii*	*Bulimina aculeata*	*Bulimina alazanensis*	*Bulimina jarvisi*
9-2: 48-50	71.28	29.40		5.32	10.96	0.66	3.65	12.62
9-3: 48-50	72.78	30.00		1.99	8.61	0.33	3.64	17.55
9-4: 48-50	74.28	30.60	Early Oligocene Group III	3.13	5.64	3.45	4.39	9.72
9-4: 97-99	74.75	30.80		5.33	3.33	2.00	5.00	0.00
9-4: 148-150	75.24	31.00		3.53	11.86	0.64	6.09	0.00
9-5: 44-46	75.74	31.20		3.36	7.38	0.34	0.34	0.00
9-5: 97-99	76.25	31.40		3.33	4.00	1.00	7.33	0.33
9-5: 148-150	76.74	31.60		3.15	3.79	0.00	3.47	3.47
9-6: 45-47	77.25	31.80	Early Oligocene Group II	5.81	1.61	0.65	0.32	0.65
9-6: 101-103	77.79	32.00		2.97	6.60	0.00	0.33	1.32
9-6: 148-150	78.24	32.20		1.31	7.84	3.59	1.63	0.65
10-1: 26-28	79.06	32.60		8.67	7.00	0.33	5.00	1.67
10-1: 74-76	79.52	32.80		2.59	10.03	0.32	5.18	10.68
10-1: 124-126	80	33.00	Early Oligocene Group I	2.52	2.21	0.00	1.89	9.15
10-2: 22-24	80.52	33.20		1.61	6.43	0.00	8.04	0.00
10-2: 77-79	81.05	33.40		3.25	5.05	0.36	14.08	0.00
10-2: 126-128	81.52	33.60	earliest Oligocene	2.67	2.33	1.67	2.67	0.00
10-3: 29-31	82.09	33.80		7.79	0.65	3.90	9.09	0.00
10-3: 76-78	82.54	34.00		2.97	3.30	8.58	1.98	0.00
10-3: 118-120	82.94	34.20		1.66	2.66	7.31	2.66	0.00
10-4: 27-29	83.57	34.40		9.19	1.06	4.59	6.01	0.00
10-4: 78-80	84.06	34.60		6.91	0.99	3.95	3.62	0.66
10-4: 130-132	84.56	34.80		5.50	3.78	1.72	5.15	0.00
10-5: 26-28	85.08	35.00		3.97	5.30	1.32	11.59	0.00
10-5: 80-82	85.56	35.20	Late Eocene	2.89	3.22	3.22	11.25	0.00
10-5: 130-132	86.09	35.40		7.40	1.93	0.96	18.97	0.32
10-6: 25-27	86.55	35.60		0.68	10.96	3.08	9.93	0.00
10-6: 74-76	87.02	35.80		1.42	9.93	0.35	3.55	1.42
10-7: 25-27	87.55	36.00		9.27	10.60	0.00	1.99	0.99
11-1: 23-24	88.53	36.40		4.95	0.66	0.33	16.50	0.33
11-2: 20-22	90	37.00		6.55	6.85	4.46	10.12	3.57

Core Section	*Cassidulina subglosa*	*Cassidulina spinosa*	*Chrysalonogonium lamella*	*Cibicidoides kullenbergi*	*Cibicidoides mollis*	*Cibicidoides mundulus*	*Cibicidoides pseudo*	*Dentalina mucronata*	*Ellipsolagena barri*
9-2: 48-50	0.66	0.00	0.00	1.00	1.33	1.33	1.33	0.66	0.00
9-3: 48-50	1.32	0.00	0.00	1.99	1.99	1.99	1.99	1.99	0.00
9-4: 48-50	1.57	0.00	0.00	1.57	3.13	3.13	1.57	2.19	0.00
9-4: 97-99	3.67	0.00	0.00	3.33	4.33	5.67	0.33	3.33	0.00
9-4: 148-150	0.96	0.00	0.00	5.45	3.21	3.21	0.00	3.53	0.00
9-5: 44-46	3.36	0.00	0.00	3.36	5.03	6.71	0.00	2.68	0.00
9-5: 97-99	0.00	0.00	1.33	1.00	2.67	7.33	0.33	2.00	0.00
9-5: 148-150	0.32	0.00	0.63	1.89	2.21	4.73	0.32	1.58	0.00
9-6: 45-47	1.29	0.00	0.00	0.00	4.19	5.16	0.00	6.45	0.00
9-6: 101-103	0.00	0.00	0.33	1.65	1.65	2.64	0.33	2.31	0.00
9-6: 148-150	0.65	0.00	0.00	2.29	4.25	3.92	0.00	0.98	0.00
10-1: 26-28	0.00	0.33	0.33	0.33	0.33	3.67	0.33	0.00	0.00
10-1: 74-76	0.32	0.00	0.65	3.24	0.97	3.56	0.00	0.32	0.00
10-1: 124-126	1.58	0.00	0.00	3.15	3.79	6.31	0.95	1.58	0.00
10-2: 22-24	1.61	0.00	0.00	5.47	4.18	8.04	1.29	0.64	0.00
10-2: 77-79	0.00	0.00	0.36	7.22	0.00	9.03	3.61	0.72	0.00
10-2: 126-128	2.33	0.00	0.00	6.67	4.00	7.67	0.67	0.33	0.00
10-3: 29-31	0.65	0.00	0.00	3.25	4.22	4.87	0.32	1.95	1.62
10-3: 76-78	1.65	0.00	0.00	8.25	5.61	8.25	0.66	0.33	0.00
10-3: 118-120	1.99	0.00	0.00	2.99	2.66	5.65	3.32	0.00	0.00
10-4: 27-29	1.06	0.00	0.00	6.71	6.01	9.89	1.41	0.00	0.00
10-4: 78-80	1.32	0.00	0.00	3.29	6.58	11.51	2.63	0.33	0.00
10-4: 130-132	0.69	0.00	0.00	4.81	6.53	7.90	11.34	0.34	0.00
10-5: 26-28	0.66	0.00	0.00	2.65	5.96	5.30	3.64	0.99	0.00
10-5: 80-82	1.61	0.00	0.00	4.82	1.93	4.82	0.64	1.93	0.00
10-5: 130-132	1.29	0.00	0.32	0.64	2.57	2.25	4.18	0.96	0.00
10-6: 25-27	0.34	0.00	0.00	3.42	3.42	5.14	0.34	0.34	0.00
10-6: 74-76	0.35	0.00	0.00	1.06	3.55	2.48	0.35	1.42	0.00
10-7: 25-27	1.66	0.00	0.00	3.31	4.97	7.95	0.00	0.66	0.00
11-1: 23-24	1.65	0.00	0.00	3.30	3.30	4.62	1.98	0.33	0.00
11-2: 20-22	0.89	0.00	0.00	0.00	3.27	0.89	0.30	0.60	0.00

Core Section	*Ellipsolagena decurta*	*Entosolenia acuta*	*Entosolenia stap*	*Evolvecassidulina sp. A*	*Fursenkonia pauciloculata*	*Glandulina laevigata*	*Globocassidulina subglosa*	*Gyroidinoides grimsdaii*	*Gyroidinoides lamarckiansis*
9-2: 48-50	0.00	1.66	0.00	0.00	0.00	1.00	1.33	1.33	0.00
9-3: 48-50	0.00	0.99	0.00	0.00	0.33	0.33	4.97	0.66	0.00
9-4: 48-50	0.00	0.63	0.94	0.00	0.63	0.63	15.67	0.94	0.00
9-4: 97-99	0.00	1.33	0.00	0.00	1.33	1.67	13.33	1.33	0.00
9-4: 148-150	0.00	0.00	0.64	0.00	1.28	2.24	11.22	1.28	0.00
9-5: 44-46	0.00	0.00	0.00	0.00	0.34	0.67	18.46	3.02	0.00
9-5: 97-99	0.00	0.67	0.00	0.00	1.33	1.33	13.33	0.67	0.00
9-5: 148-150	0.00	0.63	0.00	0.00	0.95	0.95	11.99	5.05	0.00
9-6: 45-47	0.00	0.00	0.00	0.00	0.00	0.00	3.23	0.65	0.00
9-6: 101-103	0.00	0.00	0.00	0.00	0.33	2.31	1.98	2.64	0.00
9-6: 148-150	0.00	0.65	0.00	0.00	0.33	0.98	6.54	0.98	0.00
10-1: 26-28	0.00	0.00	0.00	0.00	1.00	0.00	6.67	0.33	3.00
10-1: 74-76	0.00	0.32	0.00	0.00	0.00	1.29	9.71	0.32	0.00
10-1: 124-126	0.00	0.00	0.00	0.00	0.00	0.32	17.35	0.00	0.00
10-2: 22-24	0.00	0.32	0.00	0.00	0.00	0.00	15.11	0.32	0.00
10-2: 77-79	0.00	0.00	0.00	0.00	0.36	0.00	14.44	1.08	1.81
10-2: 126-128	0.00	0.33	0.00	0.67	1.00	1.00	13.33	1.33	0.67
10-3: 29-31	0.97	2.27	0.00	0.00	0.00	1.30	7.79	6.49	0.00
10-3: 76-78	0.00	0.00	0.00	0.00	0.00	0.00	23.10	1.65	0.00
10-3: 118-120	0.00	0.00	0.00	0.00	0.33	1.33	6.64	3.32	0.00
10-4: 27-29	0.00	0.35	0.00	0.00	0.00	0.00	8.13	3.53	0.00
10-4: 78-80	0.00	0.00	0.00	0.00	0.00	0.00	14.80	2.30	0.00
10-4: 130-132	0.00	0.34	0.00	0.00	0.00	0.00	6.87	0.00	1.03
10-5: 26-28	0.00	0.00	0.00	0.00	0.00	0.00	13.25	1.32	0.00
10-5: 80-82	0.00	0.00	0.00	0.00	0.00	0.00	6.43	4.18	0.00
10-5: 130-132	0.00	0.64	0.00	0.00	0.00	0.00	7.72	0.32	0.00
10-6: 25-27	0.00	0.00	0.00	0.00	0.00	1.37	6.85	1.71	1.03
10-6: 74-76	0.00	0.00	0.00	0.00	0.35	0.35	7.09	3.55	1.06
10-7: 25-27	0.00	0.00	0.00	0.00	0.66	0.33	8.28	1.99	0.99
11-1: 23-24	0.00	0.00	0.00	0.00	0.00	0.00	9.57	6.27	0.00
11-2: 20-22	0.00	0.60	0.00	0.00	1.19	0.60	2.98	3.57	0.00

Core Section	*Gyroidinoides planulatus*	*Hoeglundia sp. A*	*Karriella bradyi*	*Lagena asperoides*	*Lagena auriculata*	*Lagena sulcata*	*Nodosaria sp. A*	*Nodosaria sp. B*	*Nogenerina rohri*
9-2: 48-50	0.33	0.00	0.00	0.00	0.00	2.99	0.66	0.00	1.66
9-3: 48-50	0.66	0.66	0.00	0.00	0.66	1.32	0.66	0.00	3.97
9-4: 48-50	0.31	0.63	0.00	0.00	0.00	0.63	1.57	0.00	2.19
9-4: 97-99	0.00	0.00	0.00	0.00	0.67	1.67	0.00	0.00	3.33
9-4: 148-150	0.00	0.32	0.32	0.00	0.32	1.60	0.32	0.00	3.85
9-5: 44-46	0.00	0.34	0.00	0.00	1.01	0.67	3.36	0.00	2.01
9-5: 97-99	0.00	0.00	1.67	0.00	0.33	1.00	0.00	0.00	3.33
9-5: 148-150	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	1.58
9-6: 45-47	0.00	0.00	0.00	0.00	0.00	0.65	0.00	0.00	5.48
9-6: 101-103	0.00	0.00	0.00	0.00	0.33	1.32	0.00	0.00	3.63
9-6: 148-150	0.00	0.00	0.00	0.00	0.98	2.29	0.33	0.00	1.96
10-1: 26-28	0.33	0.33	0.67	0.00	0.33	1.33	0.67	0.00	0.33
10-1: 74-76	0.00	0.32	0.00	0.00	0.97	2.59	2.91	0.00	1.62
10-1: 124-126	0.00	0.63	0.00	0.00	0.95	3.47	0.95	0.00	4.10
10-2: 22-24	0.00	0.00	0.00	0.00	0.00	2.25	3.22	0.00	1.61
10-2: 77-79	0.36	0.00	0.00	2.17	0.00	2.53	0.72	0.00	0.36
10-2: 126-128	0.00	0.33	0.00	1.67	0.00	3.00	1.00	0.33	1.33
10-3: 29-31	0.00	0.97	0.00	1.62	0.32	1.95	2.27	0.00	1.62
10-3: 76-78	0.00	0.00	0.00	0.00	2.31	0.00	3.63	0.00	0.66
10-3: 118-120	0.00	0.33	0.00	0.00	0.00	1.66	1.33	0.00	1.00
10-4: 27-29	0.00	0.71	0.35	0.00	0.00	2.47	1.41	0.00	2.12
10-4: 78-80	2.30	0.66	0.00	0.00	0.00	0.33	9.54	0.00	1.32
10-4: 130-132	0.34	0.00	0.00	0.00	0.00	1.03	1.03	0.00	1.72
10-5: 26-28	0.00	0.33	0.00	0.00	0.33	1.32	0.00	0.00	0.33
10-5: 80-82	0.32	0.00	0.00	0.00	0.32	0.96	0.00	0.00	1.29
10-5: 130-132	0.00	0.32	0.00	0.00	0.32	1.29	4.82	0.00	1.93
10-6: 25-27	0.00	4.11	0.00	0.00	0.00	0.34	1.71	0.00	0.68
10-6: 74-76	0.00	0.00	0.00	0.00	0.35	1.77	8.51	0.00	0.71
10-7: 25-27	1.66	0.00	0.00	0.00	1.32	0.99	0.33	0.00	0.99
11-1: 23-24	0.00	0.33	0.00	0.00	0.99	0.99	0.33	0.00	0.66
11-2: 20-22	0.00	0.00	1.49	0.00	0.89	2.98	0.89	0.00	1.49

Core Section	*Nonion havanensis*	*Nuttalides truempyi*	*Nuttalides umbonifera*	*Oridosalis umbonatus*	*Pleurostomella alternans*	*Pleurostomella brevis*	*Pleurostomella obtusa*	*Protobulimina grata*	*Pullenia bulloides*
9-2: 48-50	3.99	0.00	18.94	3.32	8.97	0.66	1.66	0.00	0.00
9-3: 48-50	4.64	0.00	6.62	3.64	11.92	2.65	2.32	0.33	0.66
9-4: 48-50	1.57	0.00	4.08	6.27	8.46	0.31	0.63	0.00	0.94
9-4: 97-99	3.67	0.00	3.00	3.33	12.00	2.00	2.00	0.00	0.00
9-4: 148-150	4.49	0.00	4.81	2.24	10.58	2.56	1.92	0.00	0.32
9-5: 44-46	1.34	0.00	4.36	2.35	9.06	2.01	6.38	1.34	0.34
9-5: 97-99	20.00	0.00	3.33	7.00	5.67	1.67	2.67	0.00	0.33
9-5: 148-150	22.40	0.00	3.15	2.84	9.46	4.73	0.00	0.00	1.58
9-6: 45-47	24.19	0.00	1.61	2.26	18.71	5.81	1.94	0.00	0.32
9-6: 101-103	14.85	0.00	2.31	8.58	12.87	3.63	3.63	0.00	3.30
9-6: 148-150	7.52	0.00	6.54	9.15	16.34	4.58	3.92	0.00	2.29
10-1: 26-28	3.33	0.00	5.00	4.00	13.33	0.00	2.33	0.00	1.00
10-1: 74-76	2.27	0.00	8.74	7.77	7.44	2.27	0.97	0.00	2.59
10-1: 124-126	7.89	0.00	4.73	9.15	4.10	1.26	0.00	0.00	0.95
10-2: 22-24	3.22	0.00	7.72	0.96	7.07	1.29	0.00	0.64	1.61
10-2: 77-79	0.00	0.00	1.44	0.72	9.03	0.00	2.17	0.00	0.00
10-2: 126-128	3.33	0.00	1.67	2.33	6.67	2.00	0.00	0.33	2.67
10-3: 29-31	3.25	0.00	0.65	4.87	5.19	2.60	0.32	0.00	0.00
10-3: 76-78	0.99	4.95	0.00	4.95	3.96	1.65	0.00	0.00	0.00
10-3: 118-120	0.66	21.59	1.66	7.31	1.99	0.66	0.00	0.00	0.33
10-4: 27-29	3.18	3.53	0.71	2.12	1.06	0.35	0.00	1.77	0.00
10-4: 78-80	1.32	2.63	0.00	4.93	2.63	1.64	0.00	1.64	0.66
10-4: 130-132	0.69	15.46	1.72	5.15	3.44	1.03	0.34	1.72	1.72
10-5: 26-28	1.66	14.90	0.66	5.30	2.65	0.66	0.33	0.00	0.33
10-5: 80-82	0.96	11.25	1.29	9.32	7.40	2.89	0.96	0.00	0.64
10-5: 130-132	1.29	16.08	1.61	4.82	4.50	0.64	0.00	0.00	0.96
10-6: 25-27	0.34	8.56	1.37	8.90	9.93	0.68	0.68	0.00	0.00
10-6: 74-76	0.35	14.18	0.71	9.93	8.16	1.06	1.77	0.00	0.35
10-7: 25-27	0.33	13.25	1.32	4.30	7.28	0.66	0.00	0.00	0.66
11-1: 23-24	0.00	14.85	1.32	1.98	9.24	0.99	0.00	0.33	1.32
11-2: 20-22	0.60	2.38	0.60	4.17	8.04	3.87	0.00	7.14	1.19

Core Section	*Pullenia quinqueloba*	*Pullenia subcarinata*	*Pullenia salisburyi*	*Pulvulinella mexicanus*	*Robulus occidentalus*	*Robulus plumeri*	*Siphonodosaria abyssorum*	*Siphonodosaria quadrulata*	*Siphonodosaria spinosa*
9-2: 48-50	0.00	0.00	0.00	8.31	0.66	1.00	0.00	0.00	0.00
9-3: 48-50	0.33	0.00	0.00	1.32	0.00	0.66	0.00	0.33	0.00
9-4: 48-50	0.63	0.00	0.00	2.19	0.31	2.19	0.00	0.94	0.00
9-4: 97-99	1.67	0.00	0.00	0.00	1.00	2.33	2.67	1.00	0.00
9-4: 148-150	0.64	0.00	0.00	0.00	0.64	4.49	0.00	0.32	0.32
9-5: 44-46	0.00	0.00	0.00	0.00	0.34	0.00	0.34	0.34	0.00
9-5: 97-99	0.00	0.00	0.00	0.33	0.00	0.67	0.00	0.33	0.00
9-5: 148-150	0.00	0.00	0.32	0.00	0.00	1.58	0.32	0.63	0.00
9-6: 45-47	0.00	2.58	0.00	0.00	0.00	0.65	0.32	1.29	0.00
9-6: 101-103	0.33	0.99	0.33	0.00	0.00	0.33	0.33	0.00	0.00
9-6: 148-150	0.65	0.00	0.00	2.29	0.00	0.33	0.65	0.00	0.00
10-1: 26-28	1.00	3.67	3.67	0.00	0.00	0.00	0.67	0.00	0.00
10-1: 74-76	0.00	0.00	0.00	0.00	0.97	1.29	0.65	2.59	0.00
10-1: 124-126	0.00	0.32	0.00	0.00	1.58	1.58	0.32	0.95	0.00
10-2: 22-24	1.29	0.32	0.00	1.61	1.29	1.61	7.07	0.64	0.00
10-2: 77-79	0.00	1.44	0.72	0.00	0.00	0.00	7.22	0.00	0.00
10-2: 126-128	3.33	0.67	0.67	0.00	2.33	8.33	0.67	0.00	0.00
10-3: 29-31	3.25	0.00	0.00	0.32	2.27	2.60	0.32	0.00	0.00
10-3: 76-78	0.33	0.00	0.33	0.00	0.99	2.31	0.00	0.66	0.00
10-3: 118-120	0.66	0.00	0.00	2.33	1.00	4.65	1.33	0.66	0.00
10-4: 27-29	2.83	0.00	0.35	2.83	3.18	4.24	3.89	0.35	0.00
10-4: 78-80	0.00	0.00	0.33	0.00	0.00	0.00	5.26	0.00	0.00
10-4: 130-132	0.00	0.00	0.34	1.72	0.34	1.72	1.03	0.00	0.00
10-5: 26-28	0.00	0.00	0.00	5.96	0.00	1.99	2.65	0.00	0.00
10-5: 80-82	0.00	0.00	0.00	1.61	0.64	0.00	4.18	0.00	0.00
10-5: 130-132	0.32	0.00	0.32	1.93	0.00	0.00	5.14	0.00	0.00
10-6: 25-27	0.34	0.00	0.34	2.40	0.68	5.14	2.74	0.00	0.00
10-6: 74-76	0.35	0.35	0.35	0.35	0.00	0.00	8.87	0.00	0.00
10-7: 25-27	0.00	1.32	0.00	0.33	1.66	0.00	1.32	0.00	0.00
11-1: 23-24	0.00	0.00	0.00	0.00	0.99	1.32	4.95	0.00	0.00
11-2: 20-22	0.30	0.00	0.00	0.00	0.30	0.89	4.46	0.00	0.00

Core Section	*Stilostomella abyssorum*	*Stilostomella consobrina*	*Stilostomella subspinosa*	*Vulvulina jarvisi*
9-2: 48-50	0.00	1.99	0.00	0.00
9-3: 48-50	0.00	2.98	2.65	0.33
9-4: 48-50	0.31	1.25	4.70	0.94
9-4: 97-99	0.00	2.00	2.33	0.00
9-4: 148-150	0.32	2.56	1.92	0.00
9-5: 44-46	0.00	6.04	3.36	0.00
9-5: 97-99	0.00	3.00	0.67	0.00
9-5: 148-150	0.00	4.73	0.95	0.00
9-6: 45-47	0.00	2.58	1.61	0.00
9-6: 101-103	0.33	1.65	13.86	0.00
9-6: 148-150	0.00	1.63	1.63	0.33
10-1: 26-28	1.67	2.33	11.67	3.33
10-1: 74-76	0.00	3.24	1.29	0.00
10-1: 124-126	0.00	3.15	3.15	0.00
10-2: 22-24	0.00	1.93	0.64	0.96
10-2: 77-79	0.72	9.03	0.00	0.00
10-2: 126-128	0.00	7.67	0.33	0.00
10-3: 29-31	0.65	2.92	4.87	0.00
10-3: 76-78	0.33	2.64	2.97	0.00
10-3: 118-120	0.33	5.98	1.66	0.33
10-4: 27-29	0.35	3.89	0.35	0.00
10-4: 78-80	0.00	2.96	2.63	0.33
10-4: 130-132	0.00	1.03	0.69	1.72
10-5: 26-28	0.33	0.99	3.31	0.00
10-5: 80-82	1.93	1.93	4.18	0.96
10-5: 130-132	0.00	1.93	0.64	0.64
10-6: 25-27	0.34	1.37	0.68	0.00
10-6: 74-76	0.35	2.84	0.35	0.00
10-7: 25-27	0.66	7.28	0.00	0.66
11-1: 23-24	0.66	2.64	1.32	0.99
11-2: 20-22	0.60	8.63	2.68	0.00

APPENDIX C

FORAMINIFERA THAT OCCUR IN ABUNDANCES GREATER THAN 5%

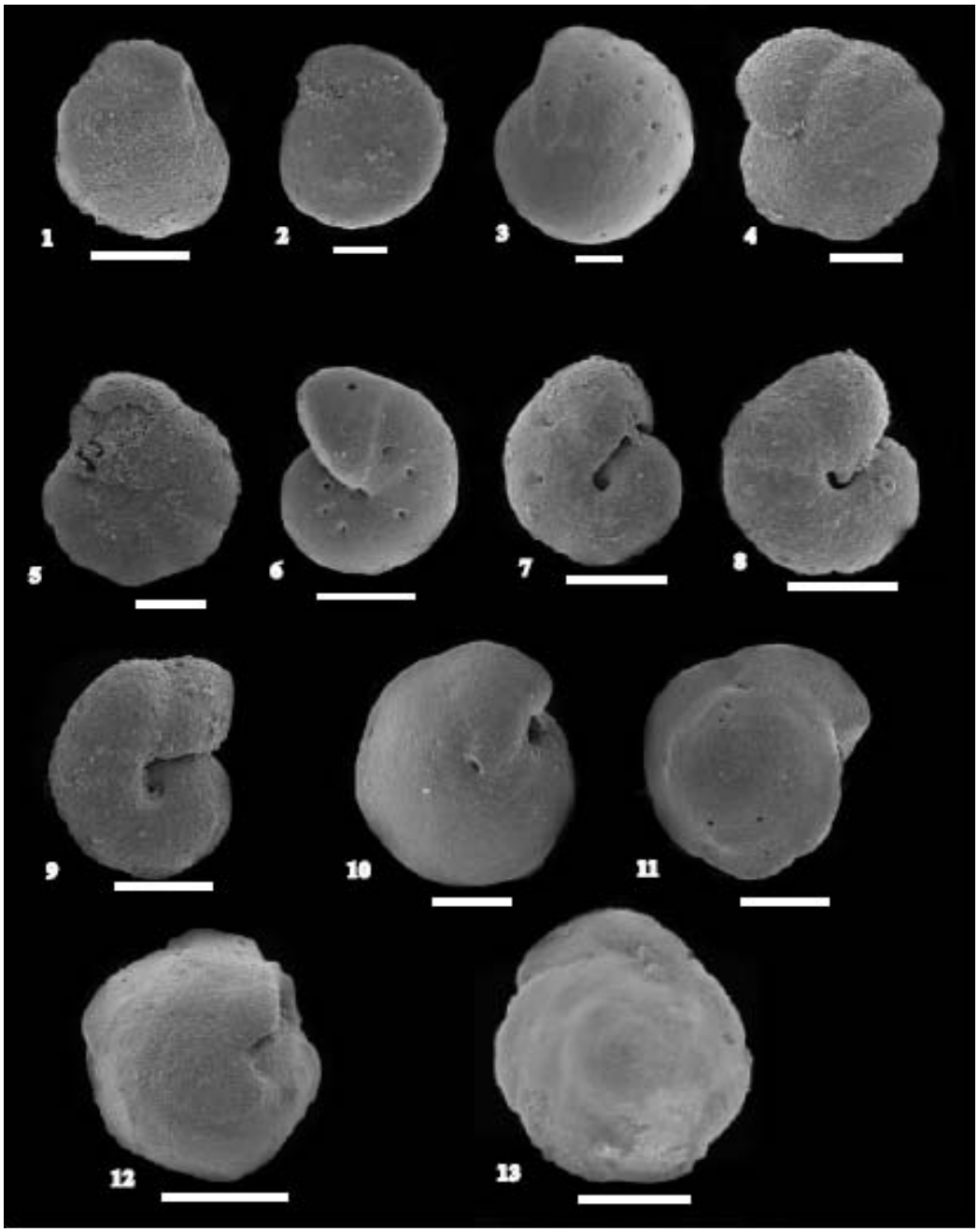

Plate 1 of benthic foraminifera from Shatsky Rise; scale bar = 100 mm. 1. Globocassidulina subglosa 2. *Cibicidoides mundulus* 3. *Cibicidoides pseudogenerina* 4. *Cibicidoides mollis* 5. *Cibicidoides sp.* 6. *Gyroidinoides lamarckiansis* 7-8. *Nonion havanensis* 9. *Anomalinoides alazanensis* 10-11. *Oridosalis umbonatus* 12. *Nuttalides truempyi* 13. *Nuttalides umbonifera*

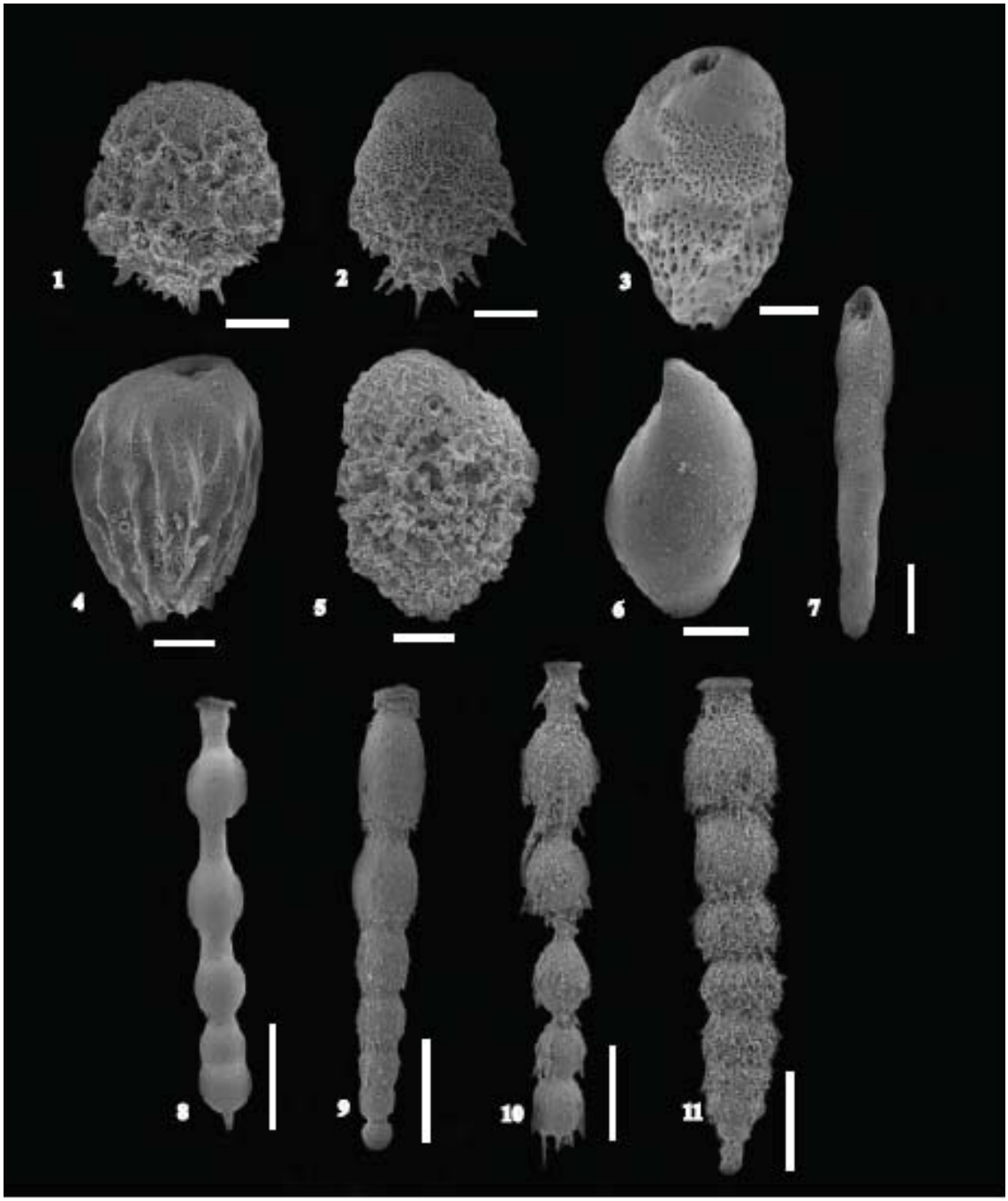

Plate 2 of benthic foraminifera from Shatsky Rise; scale bar = 100 mm. 1-2. *Bulimina aculeata* 3. *Bulimina jarvisi* 4. *Bulimina alazanensis* 5. *Bolivina huneerii* 6. *Pleurostomella obtusa* 7. *Pleurostomella alternans* 8. *Stilostomella abyssorum* 9. *Stilostomella consobrina* 10. *Stilostomella subspinosa* 11. *Siphonodosaria subspinosa*

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